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EVALUATIONS OF INSULATION MATERIALS
AND COMBINATIONS FOR BULKHEAD FIRE
PROTECTION

NAVY CONTRACT N00173-80-C-0413

EVALUATION OF INSULATION MATERIALS AND COMBINATIONS FOR BULKHEAD FIRE PROTECTION

R. S. Wulliman
Manville Service Corporation
Research and Development Center
Ken-Caryl Ranch
Denver, Colorado 80217

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NAVAL RESEARCH LABORATORY
4555 Overlook Avenue, S.W.
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

The extensive use of aluminum in the bulkheads and superstructure of Naval vessels has introduced a need for a more effective fire protection system at a lower weight per square foot than traditionally utilized systems. The objectives of ~~Navy~~ Contract ~~N00173-80-C-0413~~ were:

1. To study a variety of insulation materials and systems for their fire protection and weight per square foot characteristics, and,

2. To evaluate insulation materials and systems properties to assist in the choice of the most efficient material or system for the range of fire protection and weight per square foot criteria.

The objectives were accomplished through a combination of extensive computer studies of materials using the HEATING5 computer program and supportive small scale laboratory fire testing using a two foot by two foot furnace. Most studies were conducted using the ASTM-E119 time/temperature curve as the simulated fire. Several types of materials and systems were evaluated, including refractory fiber insulations, opacified particulates, foam, mineral fiber, and intumescent paint coatings.

Large scale fire testing contracted by the Navy (NAVSEC Report No. 6101-33, dated September 2, 1977) showed 1-inch 4 pcf CERAFELT refractory fiber to pass the criterion that the protected 1/4 inch aluminum plate could not exceed 450°F after 30 minutes exposure to the ASTM-E119 time/temperature curve on the hot side. The same material in simulation using the HEATING5 computer program allowed the aluminum plate to reach 450°F after 25.5 minutes. This was used as a "baseline" material; all other evaluated materials were judged based on the 25 minute rating and a 0.5 psf system weight.

An opacified particulate material, flexible MIN-K, proved in computer evaluation to provide better fire protection (30.5 minutes) at a lower weight per square foot (0.40 psf) than the baseline material. Additionally, installation and replacement costs may be lower for the flexible MIN-K since the surface glass cloth is already stitched onto the

material. Also, the MIN-K is more durable than CERAFELT refractory fiber, although the product is considerably more expensive than the refractory fiber product. A combination of flexible MIN-K and CERAFELT was also found to be equal in performance, but lighter than the current CERAFELT standard.

Equations were developed to assist in future studies of materials for fire protection. The equations approximate the fire protection ability of a material based on its physical properties, specifically $C \cdot \rho$ and $\frac{C}{\rho c_p}$, where:

C = Thermal conductance, $Btu/hr \cdot ft^2 \cdot {}^oF$
ρ = Density, pcf
c_p = Specific heat, $Btu/lb \cdot {}^oF$

The equations, given in the body of the report, apply individually to refractory fibers, opacified particulates, and material combinations. They can be used only as a tool for approximation, and should not be considered absolute.

Intumescent paint coatings were evaluated using the small scale laboratory furnace. (HEATING5 does not have the capability to simulate intumescence.) The coating added as much as 4.5 minutes to a material's "rating" while adding only 0.057 psf to the system weight.

It is recommended that:

1. Large scale laboratory fire tests be conducted on the Flexible MIN-K (1/2-inch, 8 pcf core) product, the Flexible MIN-K (1/4-inch, 8 pcf core) plus 4 pcf CERAFELT (1/4-inch) system, and the 6 pcf Q-Fiber (1 inch) product in conjunction with the 4 pcf CERAFELT (1-inch) standard to confirm the HEATING5 results.

2. If the large scale laboratory fire tests confirm the HEATING5 data, a program be initiated to establish the techniques to combine the materials (Flexible MIN-K and CERAFELT) into a single product, to apply it to the various bulkhead and structural configurations, and to evaluate the cost effectiveness of the new system.

3. Consideration be given to a program to improve the thermal performance of existing refractory

fiber products (i.e., Q-Fiber) through the introduction of opacifiers.

4. An intumescent paint system equivalent to the Ocean Chemicals, Inc., System 63/3342 be incorporated into the large scale laboratory fire tests to confirm the findings of the small scale fire tests.

5. The equations developed to describe the thermal response of the aluminum bulkhead be utilized to generate comparisons between known materials and new materials, or to establish the necessary properties of a material for a certain degree of protection.

Details of evaluation methods, results and conclusions are located in the body of this report.

INTRODUCTION

Background

Aluminum, with its high strength-to-weight ratio, is being used extensively in the superstructure of combat ships in order to achieve greater performance. However, since aluminum begins to lose strength above about 450°F, it is necessary to protect the structure from fire for at least some finite period of time. At present, this time is 30 minutes when the insulation/bulkhead system is subjected to the ASTM-E119 time/temperature fire conditions.

The Navy Ship Engineering Center has sponsored several studies dating back to 1974 which concluded that lightweight materials were available that could withstand the fire environment and protect the aluminum structure (see References). These materials are low density (3-4 pcf) refractory fiber felts, one inch thick, faced with glass cloth (similar to Navy Hull Board MIL-I-742). The total weight of this currently approved insulation composite is 0.5 pounds per square foot.

Specific thermal insulation system characteristics which are of concern may be summarized in the approximate order of their importance as follows:

a. Weight per square foot
b. Fire protection
c. Room temperature thermal protection
d. Thickness
e. Cost
f. Appearance
g. Acoustical properties

Rationale

This program undertook the study of many different materials and combinations of materials in order to provide the Navy with a broad spectrum of capabilities, as well as the flexibility to adjust the insulation system to meet changing structural design requirements.

The problems associated with providing the best steady state insulation for the least weight per square foot, and providing a material which will block the penetration of high heat fluxes for short periods of time were first described when the early manned spacecraft were still in the design stages. The term used to describe the former situation is $k\rho$, or thermal conductivity multiplied by density. The material having the lowest $k\rho$ factor would be the most efficient steady state insulation on a weight basis.

In contrast, the ability of a material to stop the passage of a high heat flux in a transient situation is measured by $k/\rho c_p$, thermal conductivity divided by density and specific heat, and is called diffusivity. The lower the diffusivity, the greater the capability of a material to resist this flow of heat. (This assumes no chemical or physical change during the transient heating period.) It will be noted that if we assume that the specific heat for most insulating materials is about the same, the materials which would be best under both steady state and transient situations would require an unrealistically low thermal conductivity. Since no such material exists, a compromise is necessary. In most instances, the compromise was based upon the space (thickness) available as the insulation cavity.

In the case of ship bulkheads, space available for insulation is not as critical as in a manned spacecraft. The principles of the $k\rho$ and diffusivity factors are still appropriate, however. Two classes of materials stand out as best in each category. The lowest $k\rho$ factor is obtained with 3 to 4 pcf fibrous felts having a fiber diameter of about 1.2 microns. Although their density is the same as the conventional refractory (ceramic) fiber felts currently specified, the thermal conductivity is lower due to the finer fibers. These fibers can withstand temperatures up to 2000°F.

The lowest diffusivity is obtained by a family of opacified particulate materials. These materials have thermal conductivity values below that of still air, and hence, considerably below all fibrous materials. The density of these products ranges from 8 pcf to 16 pcf for the flexible type, and up to 20 pcf for the rigid type. Both the low thermal conductivity and the high density provide these materials with excellent diffusivity values.

Between these extremes of physical properties lie many materials and combinations of materials, including the refractory fiber felts currently specified. However, it is important to establish which material, or possibly which combination of materials would be best for a specific set of criteria. The lowest weight product may not meet the transient heating requirements, while the heavier materials may not meet the weight limitations. However, a system, or combination of materials, might result in an acceptable compromise.

This program was designed to study a broad range of materials having significantly different physical characteristics of density and thermal conductivity. The intent was to establish as best as possible a model which would describe how the various physical characteristics affected the performance, and the potential for combining two materials to achieve better performance. This study also provided for the determination of the physical characteristics necessary should the temperature or time-to-temperature criteria be changed. The program was primarily a computer study backed up by a few laboratory tests on a two foot by two foot sample configuration.

Objectives

The primary objectives of this study may be summarized as follows:

a. To study a variety of insulation materials and systems for their fire protection and weight per square foot characteristics, and,

b. To evaluate insulation materials and systems properties to assist in the choice of the most efficient material or system for the range of fire protection and weight per square foot criteria.

DISCUSSION

Background

The program designed to achieve the mentioned objectives was divided into several tasks. The first task in the program was to identify the materials to be included in the study and compile property data. Selected materials were then evaluated for fire protection ability with the use of an DoE computer program entitled "HEATING5". After analysis of these results, small scale fire tests in a two-foot by two-foot furnace were done on some of the materials to compare these results with the computer study results. Subsequently, additional computer evaluations were conducted to broaden the range of possible materials and combinations thereof.

Materials Selection

Two "families" of materials first considered for the evaluations as mentioned earlier, were refractory or ceramic fibers and opacified particulates. In addition, high temperature mineral fiber and, later in the evaluation, foam type insulations were also considered. Some insulations traditionally used in shipboard fire protection applications, such as the MARINITE insulations, were not included in the investigation. The high weight per square foot and relatively poor thermal characteristics precluded their consideration for the Navy's current purposes.

Refractory Fiber - The following refractory fibers were considered in this study:

CERAFELT, 3 pcf to 10 pcf
CERABLANKET, 3 pcf to 8 pcf
CERAFORM Types 102, 106R, 103, 126, 141, 130 and 143
SAFFIL Fiber Mat, 6 pcf
THERMOFLEX II, 3 pcf to 12 pcf
FIBERFRAX LO-CON, 4 pcf to 6 pcf
Q-FIBER felt, 3 pcf to 6 pcf
MICROLITE B, 1.5 pcf to 4.5 pcf
KAOWOOL, 3 pcf to 8 pcf
CERACHROME, 6 pcf to 10 pcf
INSWOOL-HP, 4 pcf to 8 pcf

The list is by no means all-inclusive. There are other refractory fibers available on the market, but the materials listed cover the range of available fibers. (See Appendix A for the manufacturers of all the materials.)

The benefits of refractory fiber are their relatively low density and good thermal properties (compared to board or pressed products). Refractory fiber, however, is not as durable as some other choices and would require a more rigid facing or covering when installed. The cost of refractory fiber, with a few "special" exceptions is reasonable. The exceptions are high purity and/or fine fiber diameter refractory fibers, such as Q-FIBER. The added improvement in thermal values obtained with these fibers makes them attractive possibilities, however.

Opacified Particulates - The following opacified particulate materials were considered for evaluation in this study:

Lightweight Flexible MIN-K
Standard Flexible MIN-K
Mid-Range Flexible MIN-K
High Temperature Flexible MIN-K
MIN-K 1301

MIN-K 2000
MIN-K TE1400

Flexible MIN-K insulations include a glass or quartz cloth stitched to the MIN-K. The core densities can range from 8 pcf to 16 pcf. Composite weight per square foot ranges from 0.20 psf for 1/4-inch lightweight flexible MIN-K to 0.61 psf for 3/8-inch high temperature flexible MIN-K. Molded MIN-K densities (Types 1301, 2000 and TE1400) are all 20 pcf (0.42 psf per 1/4 inch of thickness). These are rigid board materials and do not include facing.

The benefits of the MIN-K materials are their extremely good thermal properties. As a result, a given thickness of MIN-K protection could be equivalent to a much greater thickness of a different material, so that even with the added density, weight per square foot may be lower. MIN-K is also more durable and has a harder or "cleaner" surface than fibrous insulation. The cost of MIN-K is, however, quite high in comparison to refractory fibers.

Other - In addition to the refractory fibers and opacified particulates, a few other types of insulations were considered including isocyanurate foam, mineral fiber, and intumescent paint.

The benefits of foam insulations are the light weight and excellent thermal properties they provide. Unfortunately, temperature service limits for foams are fairly low, around 500 °F to 600 °F. At these temperatures foams are destroyed and can release, in many cases, toxic gases when they burn. As a result, they would be suitable only for use in a multi-material configuration, insulated themselves from the fire. Deterioration would also be a problem with foams.

Mineral or glass fiber insulations, such as MICROLITE B, are good insulations and have relatively low densities. However, there are temperature limitations. A temperature of much over 800°F would fuse the glass and destroy its protection ability.

All of the materials under consideration in this project were tabulated along with their densities, thermal conductivities and specific heats. Quantification of these properties was necessary for a material to be evaluated using the HEATING5 computer program. Appendix B contains the tabulated values for each product listed which were obtained from published literature for that product. The exception is isocyanurate foam; properties were obtained from published reports on the "generic" characteristics of the material.

In addition to investigating materials, some work was conducted on the value of intumescent paint systems as an additional fire protection measure. HEATING5 is not capable of simulating the response of this coating to a fire, however, so only small scale fire tests were used to determine the added benefit of intumescent paint.

HEATING5 Evaluations

The HEATING5 computer program was developed by the Nuclear Division of the Union Carbide Corporation at Oak Ridge for the Energy Researcn and Development Administration (now DoE). The program is designed to solve steady-state and transient heat conduction problems in one, two or three dimensional Cartesian or cylindrical coordinates, or one dimensional spherical coordinates. Its capabilities include evaluation of materials that change phase, have temperature dependent properties, and/or time dependent boundary conditions.

For the present study, one-dimensional transient heat flow was assumed. Input into the program for each material evaluation included the temperature dependent thermal conductivity, the temperature dependent specific heat, density, and thickness of that particular material. The surface convection coefficient was assumed to be a constant 3 Btu/hr$\cdot$ft$^2\cdot{}^\circ$F in all cases in order to maintain a basis for comparison. The radiation shape factor in all cases was assumed to be 1.0, meaning that all radiation was "seen" by both surfaces. Also, boundaries were assumed to be black bodies. Boundary conditions were time-dependent. For the majority of the evaluations, the ASTM-E119 time-temperature curve was used to simulate the fire. A 2000°F temperature pulse was also simulated with several materials. The "cold side" of the configuration in all cases was maintained at 68°F. Some evaluations were done assuming the 1/4 inch aluminum plate was insulated on one side, with the other side exposed to a constant 68°F ambient. The majority of the evaluations, however, were done assuming the plate was insulated on both sides with the same material(s). Figures 1 and 2 show the assumed configurations.

It must be noted that computer evaluation results are not absolute; actual fire tests of the materials evaluated will not yield the exact same results. In the computer evaluations, surface and radiative coefficients and ambient conditions are held constant with each material. In fire tests, they may differ simply due to the temperature in the room or other factors. The computer evaluations do not account for any thermal shorts. Instead, one-dimensional heat flow is assumed. In actual fire tests, however, some degree of heat loss in other than the prescribed parallel path cannot be avoided. Also, HEATING5 is not capable of simulating the effects of organic binder burn-out, punking, or exotherming, all of which greatly impact fire test results. The HEATING5 program can, however, give a very good indication of the relative fire protection abilities of different insulations.

In order to relate HEATING5 results to reality, e.g., to what the response of the evaluated material would be in an actual fire situation, a "baseline" material was established. The material, 1-inch, 4 pcf CERAFELT, was chosen because it passed the Navy requirements in a large scale fire tested in a double configuration using the ASTM-E119 time-temperature curve, as reported in NAVSEC Report No. 6101-33, dated September 2, 1977.

Single materials were evaluated first using the HEATING5 program. Composite materials were also evaluated, as well as a few single materials with an air gap between the insulation and the plate.

The materials listed in Table 1 were evaluated using the HEATING5 program and the ASTM-E119 time-temperature curve. The aluminum plate was considered to be insulated on both sides in these evaluations.

FIGURE 1

DOUBLE INSULATED CONFIGURATION

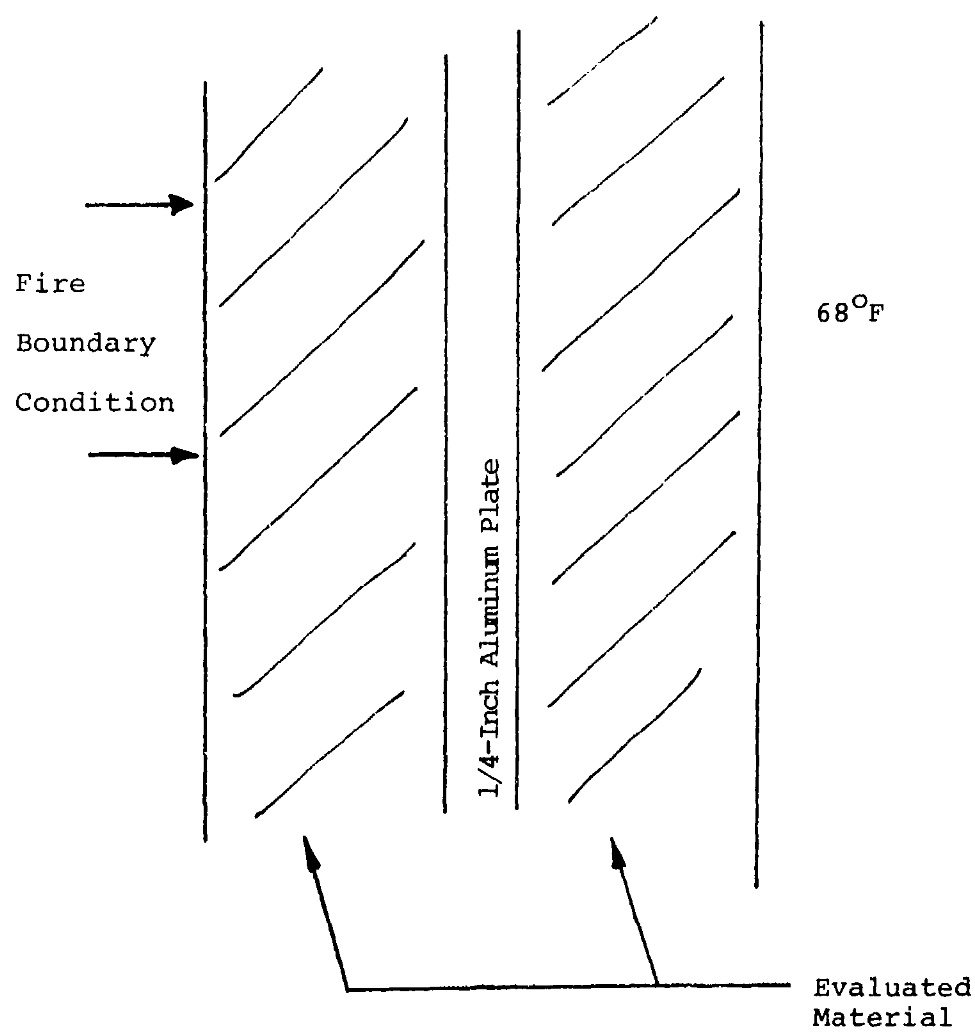


FIGURE 2

SINGLE INSULATED CONFIGURATION

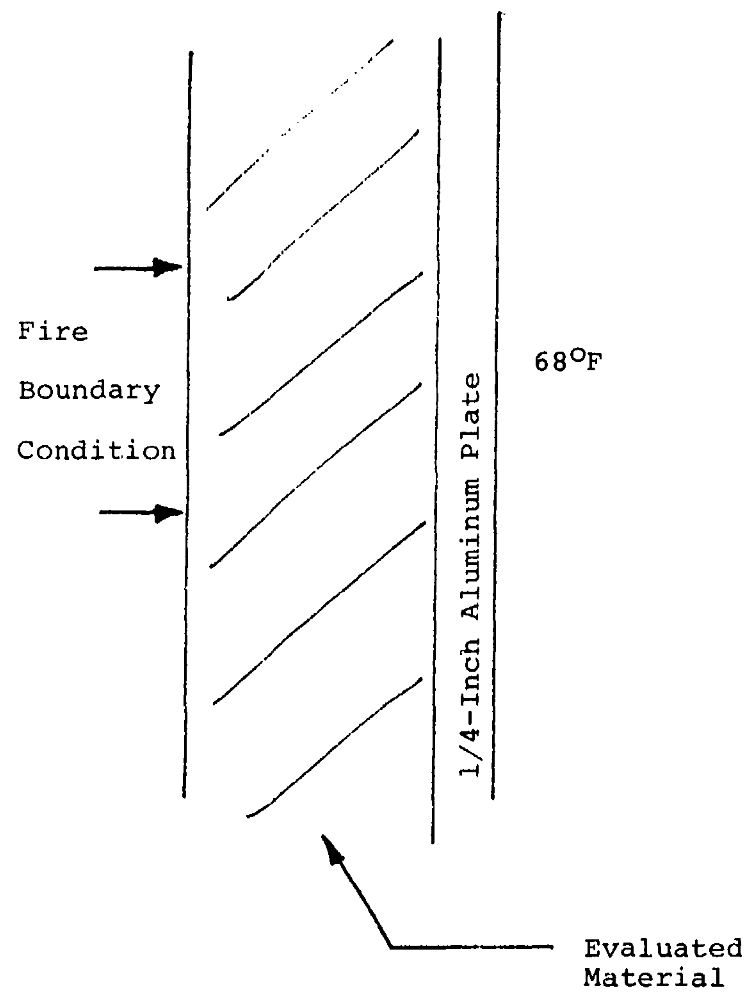


TABLE 1

MATERIALS EVALUATED USING HEATING5 DOUBLE INSULATED CONFIGURATION

ASTM-E119 TIME-TEMPERATURE CURVE

1-inch	4 pcf	CERAFELT
1-inch	8 pcf	CERAFELT
1-1/2-inch	6 pcf	CERAFIBER
3/8-inch	10 pcf	Core Lightweight Flexible MIN-K
1/2-inch	8 pcf	Core Lightweight Flexible MIN-K
2-inch	4 pcf	CERAFELT
2-inch	6 pcf	CERAFIBER
1-inch	6 pcf	Q-FIBER
1-inch	18.5 pcf	Type 126 CERAFORM
1/2-inch	12 pcf	THERMOFLEX II
1-1/2-inch	6 pcf	SAFFIL FIBER
1-1/2-inch	6 pcf	LO-CON
1-1/2-inch	8 pcf	KAOWOOL
1-1/4-inch	8 pcf	INSWOOL
1-1/4 inch	6 pcf	Q-FIBER
1-1/2 inch	4.5 pcf	MICROLITE B
3/4-inch	20 pcf	MIN-K 1301
1-inch	20 pcf	MIN-K 2000
1/2-inch	20 pcf	MIN-K TE1400
3/8-inch	20 pcf	MIN-K 1301
3/8-inch	20 pcf	MIN-K 2000
3/8-inch	20 pcf	MIN-K TE1400
3/4-inch	12 pcf	THERMOFLEX II
1-inch	13.5 pcf	CERAFORM 103
1-inch	8 pcf	KAOWOOL
1/2-inch	6 pcf	Q-FIBER
1-inch	6 pcf	LO-CON

The materials shown in Table 2 were evaluated using the HEATING5 program and the ASTM-E119 time-temperature curve. The aluminum plate was assumed to be insulated on the <u>fire side only</u>.

TABLE 2

MATERIALS EVALUATED WITH HEATING5 - SINGLE SIDE INSULATED CONFIGURATION

ASTM-E119 TIME-TEMPERATURE CURVE

2-inch	4 pcf	CERAFELT
1/2-inch	8 pcf Core	Lightweight Flexible MIN-K
1-inch	8 pcf	CERAFELT
3/8-inch	10 pcf Core	Lightweight Flexible MIN-K
1 inch	4 pcf	CERAFELT
2-inch	6 pcf	CERAFIBER
1-1/2 inch	6 pcf	CERAFIBER
1-1/2 inch	6 pcf	SAFFIL
1-inch	6 pcf	Q-FIBER
1-1/2 inch	6 pcf	LO-CON
1/2-inch	12 pcf	THERMOFLEX II
1-inch	18.5 pcf	Type 126 CERAFORM
1-1/2-inch	8 pcf	KAOWOOL
1-1/4-inch	8 pcf	INSWOOL
1-1/4-inch	6 pcf	Q-FIBER
1-1/2-inch	4.5 pcf	MICROLITE B
3/4-inch	20 pcf	MIN-K 1301
1-inch	20 pcf	MIN-K 2000
1/2-inch	20 pcf	MIN-K TE1400

Table 3 lists the material combinations evaluated using the HEATING5 program and the ASTM-E119 time-temperature curve. The aluminum plate was assumed to be insulated on both sides in these evaluations. In all cases, the material listed first was the one assumed to be exposed to the fire.

TABLE 3

MATERIAL COMBINATIONS EVALUATED WITH HEATING5 - DOUBLE INSULATED CONFIGURATIONS

ASTM-E119 TIME-TEMPERATURE CURVE

1/4-inch, 18.5 pcf CERAFORM 126 + 1/2-inch, 6 pcf, Q-FIBER
1/4-inch, 8 pcf Core L.W. Flexible MIN-K + 1/4-inch, 4 pcf, CERAFELT
1/4-inch, 18.5 pcf CERAFORM 126 + 1/2-inch, 6 pcf, LO-CON
1/4-inch, 20 pcf MIN-K TE1400 + 1/4-inch 4.5 pcf MICROLITE B
1/4-inch, 8 pcf Core L.W. Flexible MIN-K + 1-inch, 4 pcf, CERAFELT
1/2-inch, 18.5 pcf CERAFORM 126 + 1/4-inch AIR GAP
1/2-inch, 12 pcf, THERMOFLEX II + 1/2-inch AIR GAP
1/2-inch, 4 pcf CERAFELT + 1-inch, 3 pcf ISOCYANURATE FOAM
1-inch, 4 pcf CERAFELT + 0.1 inch ALUMINUM SKIN
1-inch, 4 pcf, CERAFELT + 0.05-inch ALUMINUM SKIN
1-inch, 4 pcf, CERAFELT + 0.2-inch ALUMINUM SKIN
1/2-inch, 6 pcf, Q-FIBER + 1/2-inch, 3 pcf ISOCYANURATE FOAM
1/2-inch, 6 pcf, Q-FIBER + 1-inch, 3 pcf ISOCYANURATE FOAM
1/2-inch, 4 pcf, CERAFELT + 1/2-inch, 3 pcf ISOCYANURATE FOAM
1/2-inch, 4 pcf, CERAFELT + 1/4-inch, 3 pcf ISOCYANURATE FOAM
1/4-inch, 20 pcf MIN-K TE1400 + 1/2-inch, 3 pcf ISOCYANURATE FOAM
1/4-inch, 8 pcf Core L.W. Flexible MIN-K + 1/2-inch ISOCYANURATE FOAM
1/4-inch, 8 pcf Core L.W. Flexible MIN-K + 1/4-inch, 3 pcf ISOCYANURATE FOAM

The materials and combinations of materials listed in Table 4 were evaluated using the HEATING5 program and a 2000°F temperature pulse. The material listed first in the combination is the one assumed to be exposed to fire. (This evaluation condition was suggested by Mr. J. Morris to Mr. R. C. Manahan of Johns-Manville during a visit by Mr. Manahan to the Naval Ship Research and Development Center.)

TABLE 4

MATERIALS AND COMBINATIONS EVALUATED WITH HEATING5 -
DOUBLE INSULATED CONFIGURATION

2000°F TEMPERATURE PULSE

3/8-inch	20 pcf	MIN-K TE1400
1-1/4-inch	6 pcf	Q-FIBER
1-inch	18.5 pcf	CERAFORM 126
1-1/2-inch	8 pcf	KAOWOOL
1/4-inch	18.5 pcf	CERAFORM 126 + 1/2-inch, 6 pcf, Q-FIBER
1/4-inch	8 pcf Core	L.W. Flexible MIN-K + 1/4 inch, 4 pcf, CERAFELT
1/4-inch	20 pcf	MIN-K TE1400 + 1/4-inch, 4.5 pcf MICROLITE B
1-inch	6 pcf	CERAFELT
3/4-inch	12 pcf	THERMOFLEX II
2-inch	6 pcf	CERAFIBER
1/4-inch	8 pcf Core	L.W. Flexible MIN-K + 1-inch, 4 pcf, CERAFELT
1/4-inch	18.5 pcf	CERAFORM 126 +1/2-inch, 6 pcf, LO-CON
1/4-inch	13.5 pcf	CERAFORM 103 + 1/2-inch, 4 pcf, CERAFELT
1-inch	6 pcf	LO-CON

The temperatures at several nodes in the configurations were printed out so that a complete temperature profile was established. The temperature of the insulated aluminum plate was of primary importance and was graphed for each evaluation. The criterion of acceptance set forth by the Navy was that the temperature of the aluminum plate could not exceed 450°F after 30 minutes of exposure, when using the ASTM-E119 time-temperature curve. In large scale fire testing contracted by the Navy (NAVSEC Report 6101-33, mentioned previously), 1-inch 4 pcf CERAFELT, the chosen baseline material, met this requirement, the plate reaching 450°F after 30-32 minutes. A HEATING5 evaluation of 1-inch 4 pcf CERAFELT showed the aluminum plate to reach 450°F after only 25.5 minutes. As a result, all materials and combinations that were evaluated and found to prevent plate temperature from exceeding 450°F after 25 minutes when using ASTM-E119 were considered to be acceptable.

The criterion of acceptance set forth by the Navy for aluminum plate response to the 2000°F temperature pulse is a maximum of 400°F after 20 minutes. The "baseline" material, 1-inch, 4 pcf, CERAFELT, allowed the plate to reach 400°F after only 8 minutes. (The aluminum plate temperature at 20 minutes into the simulation was 881°F.) Eight minutes was considered acceptable, then, when evaluations using the 2000°F temperature pulse were conducted.

Fire Testing

As a secondary part of this contract, laboratory fire tests were conducted on a small two-foot by two-foot furnace. The configuration tested was the same as that evaluated with HEATING5 and shown in Figure 1, "double" insulated.

Thermocouples and a datalogger were used to monitor surface, ambient and aluminum plate temperatures. Placement of the thermocouples is shown in Figure 3. A control thermocouple and temperature controller were used to adhere the hot side boundary condition to the ASTM-E119 time-temperature curve.

It must be mentioned that a fire test on the scale of two-feet by two-feet cannot give a true representation of material protection ability. Error is introduced in the edge heat loss and in control response time lag. (The ASTM-E119 curve could not be duplicated exactly due to control response lags.) These errors are somewhat consistent however, and thus the small scale tests were helpful in comparing relative results with HEATING5 evaluations.

The laboratory fire tests were also necessary in testing the effectiveness of intumescent paint in adding fire protection to an insulation system. Materials were tested without the paint coating in the furnace and then again with the paint. The intumescent paint tested was Ocean Chemicals, Incorporated, System Ocean 634/3342 system. The protective contribution of the paint during a fire could not be simulated using HEATING5, but could be determined using the small scale fire test comparative results.

FIGURE 3

SMALL SCALE FIRE TESTING - 2 FOOT by 2 FOOT FURNACE

PLACEMENT OF THERMOCOUPLES

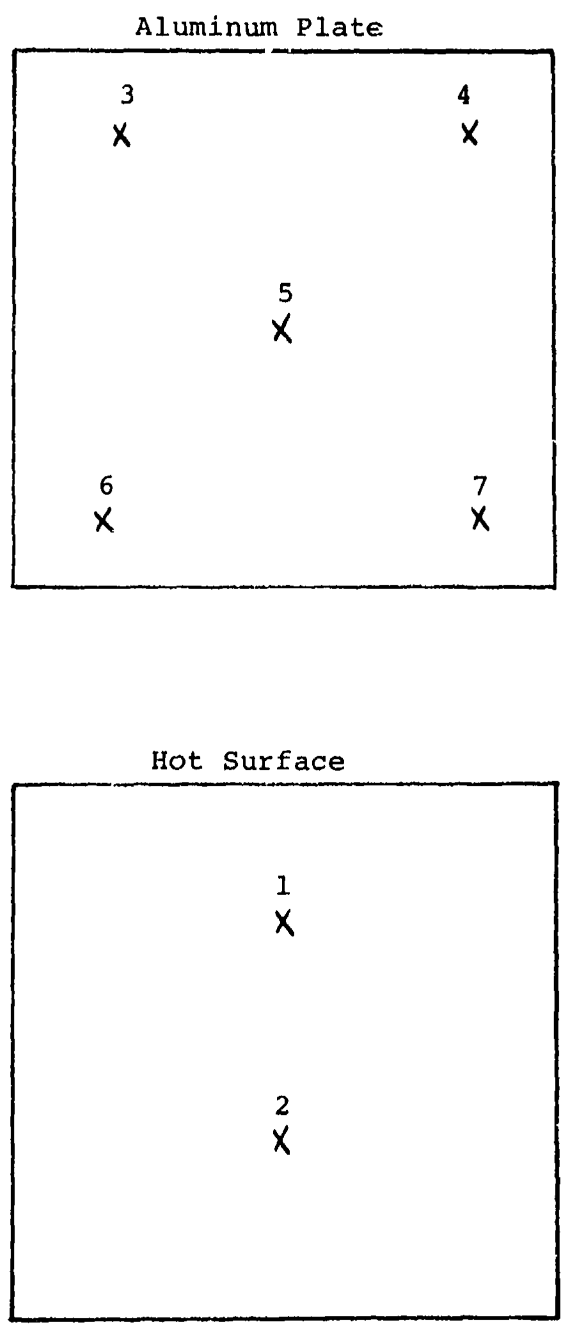


Table 5 is a list of the materials laboratory tested in the two-foot by two-foot furnace using the ASTM-E119 time-temperature curve. The aluminum plate was insulated on both sides.

TABLE 5

MATERIALS EVALUATED IN SMALL SCALE FIRE TESTS - DOUBLE INSULATED CONFIGURATION

ASTM-E119 TIME-TEMPERATURE CURVE

1-inch	18.5 pcf	CERAFORM 126
1-inch	8 pcf	KAOWOOL
3/8-inch	10 pcf	Core L.W. Flexible MIN-K
3/8-inch	20 pcf	MIN-K 1301
3/8-inch	20 pcf	MIN-K TE1400
1/2-inch	6 pcf	Q-FIBER
1-1/2-inch	8 pcf	KAOWOOL
1-inch	6 pcf	Q-FIBER
1-inch	6 pcf	LO-CON
1-inch	4 pcf	CERAFELT
1-inch	8 pcf	CERAFELT
1-1/2-inch	4 pcf	CERAFELT
1-1/2-inch	6 pcf	CERAFIBER

The last four materials listed were tested again with intumescent paint applied. A glass reinforced mylar was included on the material surfaces both with and without the intumescent paint. The purpose of the mylar was to have a paintable surface for these tests.

RESULTS

HEATING5 Evaluations

The results from the HEATING5 evaluations are given in detail in Appendix C. Both tables and graphs are included for results from the ASTM-E119 heat up and the 2000°F pulse temperature. The major part of the discussion of results, the conclusions and the recommendations, however, will be addressed to the ASTM-E119 time-temperature curve evaluations due to the greater applicability and larger data base available with this given boundary condition.

HEATING5 Evaluations - Double Side Insulation

The results discussed in the following paragraphs are from HEATING5 evaluations assuming a double-sided configuration as shown in Figure 1. This configuration is essentially the most applicable to Navy requirements; any material that can meet the criterion of acceptance in this "double" configuration, can also be assumed to meet it in a "single-side" configuration. The materials listed in Table 6 passed the "modified" requirement (explained earlier) of aluminum plate temperature maximum of 450°F after 25 minutes of exposure to the ASTM-E119 time-temperature curve. The table lists the acceptable materials in order of increasing weight per square foot.

As apparent in the table, only one material, a composite, met the 25 minute requirement and weighed less per square foot than the baseline material, 1-inch 4 pcf CERAFELT. The composite consisted of 1/4-inch flexible MIN-K and 1/4-inch 4 pcf CERAFELT and weighed only 0.28 psf compared to 0.33 psf for 1-inch 4 pcf CERAFELT. An additional weight savings is realized due to the fact that the composite mentioned is glass cloth-faced in its original form. The plain CERAFELT would need an added glass cloth facing, resulting in an approximate total of 0.5 psf as currently installed. The glass cloth facing is not a significant contributor to the fire protection ability of the system. Other materials that weighed about 0.5 psf and met the 25 minute criterion included 1-inch 6 pcf LO-CON, 1-inch 6 pcf Q-FIBER, 1/4-inch MIN-K TE1400 + 1/4-inch 4.5 pcf MICROLITE B, 1/4-inch Flexible MIN-K + 1-inch 4 pcf CERAFELT and 1/2-inch, 8 pcf Core Flexible MIN-K.

TABLE 6

HEATING5 EVALUATIONS - MATERIALS TO MEET MAXIMUM 450°F
AFTER 25 MINUTES (Increasing psf Order)
Double Insulated Configuration

Material(s)	Wt.per Sq. Ft.,psf	Min. To 450°F
1/4-inch 8 pcf Core Flex. MIN-K + 1/4-inch 4 pcf CERAFELT	0.28	25
1-inch 4 pcf CERAFELT	0.33	25.5
1/2-inch, 8 pcf Core L.W. Flexible MIN-K	0.40	30.5
1-inch 6 pcf Q-FIBER	0.50	27
1-inch 6 pcf LO-CON	0.50	26
1/4-inch 20 pcf MIN-K TE1400 + 1/4-inch 4.5 pcf MICROLITE B	0.51	36
1/4-inch, 8 pcf Core Flx. MIN-K + 1 inch 4 pcf CERAFELT	0.53	42
1-1/2-inch 4.5 pcf MICROLITE B	0.56	32
3/8-inch 20 pcf MIN-K TE1400	0.62	59
3/8-inch 20 pcf MIN-K 1301	0.62	45
3/8-inch 20 pcf MIN-K 2000	0.62	50
1-1/4-inch 6 pcf Q-FIBER	0.62	32
1/4-inch 18.5 pcf CERAFORM 126 + 1/2-inch 6 pcf Q-FIBER	0.64	30
1/4-inch 18.5 pcf CERAFORM 126 + 1/2-inch 6 pcf LO-CON	0.64	28
2-inch 4 pcf CERAFELT	0.67	31
1-inch 8 pcf CERAFELT	0.67	27
1-inch 8 pcf KAOWOOL	0.67	26
1-1/2-inch 6 pcf SAFFIL	0.75	36
1-1/2-inch 6 pcf LO-CON	0.75	32
1/2-inch 18.5 pcf CERAFORM 126 + 1/4-inch AIR-GAP	0.75	29
3/4-inch 12 pcf THERMOFLEX II	0.75	28.5
1-1/2-inch 6 pcf CERAFIBER	0.75	28
1/2-inch 20 pcf MIN-K TE1400	0.83	49
1-1/4-inch 8 pcf INSWOOL	0.83	31
1-1/2-inch 8 pcf KAOWOOL	1.0	36.5
2-inch 6 pcf CERAFIBER	1.0	35
1-inch 13.5 pcf CERAFORM 103	1.12	42
3/4-inch 20 pcf MIN-K 1301	1.25	70
1-inch 18.5 pcf Type 126 CERAFORM	1.54	33
1-inch 20 pcf MIN-K 2000	1.67	85

The above listing and tables mentioned do not include results from material composites which contain foam as a component nor results of evaluations with thin aluminum skins on the fire surface of the configuration. These subjects will be discussed separately in the report.

After evaluations were completed, an attempt was made to characterize the response time in minutes to 450°F as a function of some physical property or properties of the material(s) involved. Results were plotted several times in pounds per foot squared versus time to 450°F, $k \cdot \rho$ versus time to 450°F, $\frac{k}{\rho c_p}$ versus time to 450°F, thickness versus time to 450°F, etc. The data seemed most consistently to fit a smooth curve when $C\rho$, $\frac{C}{\rho c_p}$ or some product of the two were plotted. The C in the term is conductance in Btu/hr·ft^2·°F, or thermal conductivity divided by thickness. The quantity of the material evaluated is thus taken into account in the analysis. It also became apparent during the plotting of the data that the opacified particulate and refractory fiber materials were distinctively different and could not be "lumped" together for characterization. In addition, and somewhat more obviously, the composite configurations had to be characterized separately. Therefore, three separate regressions were done to characterize the data and three separate equations were developed, one for single refractory fiber-type insulations, one for single opacified particulate-type insulations, and one for composite (two material) configurations regardless of type.

Refractory Fiber

An "all possible subsets" regression was done on the minutes to 450°F data from the HEATING5 evaluations as a function of material properties. Nineteen data points were available on single refractory fiber materials. The following combinations of $C\rho$ (A) and $\frac{C}{\rho c_p}$ (B) were considered in the regression:

Note: On properties that change with temperature such as thermal conductivity, the products property value at 1000°F was used for consistency.

A	A^2
B	A/B
A•B	B/A
$A \cdot B^2$	B^2/A
B^2	A+B

The R-square values (a statistical term) for each of the above, which show the percentage of the data variation accounted for by that particular variable, are given in Table 7.

TABLE 7

ALL POSSIBLE SUBSETS REGRESSION OF REFRACTORY FIBER

Variable*	R-Square	Percentage
B/A	0.00022	0.0
A/B	0.00735	0.7
B^2/A	0.047	4.7
B^2	0.255	25.5
A	0.275	27.5
A+B	0.309	30.9
A^2	0.327	32.7
B	0.358	35.8
$A \cdot B^2$	0.631	63.1
A•B	0.713	71.3

* $A = C\rho$

$$B = \frac{C}{\rho c_p}$$

The regression showed that approximately 71 percent of the variation in the time to 450°F is attributable to the $C \cdot \rho \times \frac{C}{\rho c_p}$ of the material. A linear regression obtain an equation characterizing minutes to 450°F as a function of this variable yielded the following result:

$$\text{Minutes} = 35.44 - 2.37 \left(C\rho \times \frac{C}{\rho c_p}\right) \qquad \text{Equation 1}$$

The 95 percent confidence level was ±1.8 minutes, while the 90 percent confidence level was ±1.5 minutes.

Opacified Particulate

An "all possible subsets" regression was done on the minutes to 450°F data from the HEATING5 evaluations as a function of material properties. Eight data points were available on single opacified particulate materials.

The same combinations of $C\rho$ and $\frac{C}{\rho c_p}$ were considered in this regression as in the refractory fiber materials. The results, however, were different. The following R-square values were obtained in this regression:

TABLE 8

ALL POSSIBLE SUBSETS REGRESSION OF OPACIFIED PARTICULATE

Variable*	R-Square	Percentage
A^2	0.040	4.0
A	0.087	8.7
A+B	0.100	10.0
B^2/A	0.685	68.5
B/A	0.690	69.0
A•B	0.697	69.7
$A \cdot B^b$	0.700	70.0
B^2	0.706	70.6
A/B	0.743	74.3
B	0.826	82.6

* $A = C\rho$

$B = \frac{C}{\rho cp}$

The regression showed that approximately 83 percent of the variations in the time to 450°F data is attributable to the thermal diffusivity, $\frac{C}{\rho c_p}$, of the material. A linear regression to obtain an equation characterizing minutes to 450°F as a function of thermal diffusance yielded the following result:

$$\text{Minutes} = 84.78 - 222.84 \frac{C}{\rho c_p} \qquad \text{Equation 2}$$

The 95 percent confidence level was ±8.5 minutes, while the 90 percent confidence level was ±6.7 minutes.

Composite Insulations

An "all possible subsets" regression was done on the minutes to 450°F data from the HEATING5 evaluations of composite materials as a function of the materials' properties. Six data points were available on composite materials.

The following combinations of $c\rho$ (A) of the "outer" (hot) material, $C\rho$ (B) of the "inner" (cold) material, $\left(\frac{C}{\rho c_p}\right)_1$ (X) of the "outer" material, and $\left(\frac{C}{\rho c_p}\right)_2$ (D) of the inner material were considered in the regression:

A	A•X	(A•X)+(B•D)
B	A•D	A•B•X•D
X	B•X	A•B•X
D	X^2•B	A•B•D
A•B	D^2•B	A•X•D
X•D	X^2•A	B•X•D

The R-square values obtained in the regression for each of the above are shown in Table 9.

TABLE 9

ALL POSSIBLE SUBSETS REGRESSION OF COMPOSITE MATERIALS

Variable*	R-Square	Percentage
X	0.026	2.6
$D^2 \cdot B$	0.146	14.6
D	0.147	14.7
A	0.198	19.8
B	0.233	23.3
X•D	0.232	24.2
B•X•D	0.242	24.2
$X^2 \cdot B$	0.274	27.4
A•X	0.325	32.5
$X^2 \cdot A$	0.334	33.4
B•X	0.372	37.2
A•B•D	0.431	43.1
A•B	0.433	43.3
A•X+B•D	0.434	43.4
A•B•D•D	0.565	56.5
A•D	0.684	68.4
A•X•D	0.739	73.9
A•B•X	0.807	80.7

*$A = (C\rho)_1$

$B = (C\rho)_2$

$X = \left(\frac{C}{\rho c_p}\right)_1$

$D = \left(\frac{C}{\rho c_p}\right)_2$

The regression showed that approximately 81 percent of the variations in the time to 450°F data was attributable to $C\rho_1 \times C\rho_2 \times \left(\frac{C}{\rho c_p}\right)_1$, or the product of both materials' $C\rho$ properties and the "outer" material's thermal diffusivity. A linear regression of minutes to 450°F on this product yielded the following result:

$$\text{Minutes} = 42.49 - 0.0736\, C\rho_1 \cdot C\rho_2 \cdot \left(\frac{C}{\rho c_p}\right)_1 \qquad \text{Equation 3}$$

The 95 percent confidence level was ±4.7 minutes, while the 90 percent confidence level was ±3.6 minutes.

These equations are by no means meant to be absolute. Physical properties not considered may make the equations more exact. Thermal values obtained at 1000°F may not be the most representative of the material, and a nonlinear model would probably fit the curve more precisely. However, the equations can be useful in considering possible materials in the future. They can be used as a quick screening tool to sort out the most likely material candidates for further evaluation and study.

HEATING5 Evaluations - Single Side Insulation

Several materials were evaluated simulating a one-sided insulation condition as shown in Figure 2. Any insulation system found to be acceptable in regard to performance in the double sided configuration (Figure 1) would be acceptable performance-wise in the single sided application. It may be possible, however, to use a different system that would trade the excess in fire protection performance for a weight per square foot, thickness, cost or appearance improvement.

This possibility has not been examined thoroughly, but some evaluations were done. Table 10 lists all the materials evaluated in a one-sided configuration, their weight per square foot and the temperature of the aluminum plate after 30 minutes exposure to the ASTM-E119 time-temperature curve. Minutes to 450°F for the evaluations are not reported; in only two cases did the aluminum plate reach 450°F within the 120 minute period of evaluation. Only one of those, 1/2-inch 12 pcf THERMOFLEX II, reached 450°F within 30 minutes, at 13 minutes.

Table 11 shows the materials which did at least as well in evaluation as 1-inch 4 pcf CERAFELT. One material, 1/2-inch 8 pcf core lightweight flexible MIN-K was essentially equivalent to the CERAFELT in terms of fire protection ability, both just over 300 °F at 30 minutes. But the flexible MIN-K's total weight per square is 0.40 psf compared with CERAFELT plus a glass cloth facing at about 0.5 psf.

TABLE 10

HEATING5 EVALUATIONS - SINGLE SIDED CONFIGURATIONS

ASTM-E119 TIME-TEMPERATURE CURVE

(Increasing psf Order)

Material Description	Weight Per Square Foot psf	Temp. at 30 Min. °F
1-inch 4 pcf CERAFELT	0.33	304
3/8-inch 10 pcf Core L.W. Flexible MIN-K	0.35	358
1/2-inch 8 pcf Core L.W. Flexible MIN-K	0.40	307
1-inch 6 pcf Q-FIBER	0.50	281
1/2-inch 12 pcf THERMOFLEX II	0.50	669
1-1/2-inch 4.5 pcf MICROLITE B	0.56	239
1-1/4-inch 6 pcf Q-FIBER	0.62	242
2-inch 4 pcf CERAFELT	0.67	254
1-inch 8 pcf CERAFELT	0.67	300
1-1/2-inch 6 pcf SAFFIL	0.75	232
1-1/2-inch 6 pcf LO-CON	0.75	244
1-1/2 inch 6 pcf CERAFIBER	0.75	285
1/2-inch, 20 pcf MIN-K TE1400	0.83	182
1-1/4-inch 8 pcf INSWOOL	0.83	260
1-1/2-inch 8 pcf KAOWOOL	1.0	223
2-inch 6 pcf CERAFIBER	1.0	232
3/4-inch, 20 pcf MIN-K 1301	1.25	140
1-inch, 18.5 pcf Type 126 CERAFORM	1.54	264
1-inch, 20 pcf MIN-K 2000	1.67	119

TABLE 11

HEATING5 EVALUATIONS - SINGLE SIDED CONFIGURATION

MATERIALS TO PERFORM AS WELL AS BASELINE MATERIAL

(Increasing psf Order)

Material Description	Weight Per Square Foot psf	Temp. at. 30 Min. °F
1-inch 4 pcf CERAFELT	0.33	304
1/2-inch 8 pcf Core L.W. Flexible MIN-K	0.40	307
1-inch 6 pcf Q-FIBER	0.50	281
1-1/2-inch 4.5 pcf Microlite B	0.56	239
1-1/4-inch 6 pcf Q-FIBER	0.62	242
2-inch 4 pcf CERAFELT	0.67	254
1-inch 8 pcf CERAFELT	0.67	300
1-1/2-inch 6 pcf SAFFIL	0.75	232
1-1/2-inch 6 pcf LO-CON	0.75	244
1-1/2-inch 6 pcf CERAFIBER	0.75	285
1/2-inch, 20 pcf MIN-K TE1400	0.83	182
1/1/4-inch 8 pcf INSWOOL	0.83	260
1-1/2-inch 8 pcf KAOWOOL	1.0	223
2-inch 6 pcf CERAFIBER	1.0	232
3/4-inch, 20 pcf MIN-K 1301	1.25	140
1-inch, 18.5 pcf Type 126 CERAFORM	1.54	264
1-inch, 20 pcf MIN-K 2000	1.67	119

HEATING5 Evaluations - Aluminum Skin Surface

The possibility of extending the time to 450°F rating of any given material by adding a thin layer of aluminum to the surface that is exposed to the fire was investigated. CERAFELT (1-inch 4 pcf) was again used as a base material. Heating 5 evaluations of aluminum skins 0.05 inches, 0.10 inch and 0.20 inches thick were conducted. The aluminum skin added some additional fire protection to the CERAFELT. Table 12 (following) shows the response of the insulated aluminum plate with time for plain CERAFELT as well as CERAFELT with the aluminum skin at three thicknesses. Adding a 0.05 inch aluminum skin contributed 0.5 minutes to the plate's time to 450 °F. The 0.10 inch skin added 1.0 minutes and the 0.20 inch skin 1.5 minutes to the time rating of plain CERAFELT. The added weight per foot squared of each of these aluminum skins would be 0.7 psf for 0.05 inch thickness, 1.4 psf for 0.10 inch and 2.8 psf for 0.20 inch thickness.

TABLE 12

HEATING5 EVALUATIONS - ADDITION OF ALUMINUM SKIN SURFACE

DOUBLE INSULATED/ASTM-E119 TIME-TEMPERATURE CURVE

Material	Aluminum Skin Thickness Inches	Time to 450°F Minutes	Pounds Per Square Foot psf
1-inch 4 pcf CERAFELT	0.0	25.5	0.33
1-inch 4 pcf CERAFELT	0.05	26.0	1.03
1-inch 4 pcf CERAFELT	0.10	26.5	1.73
1-inch 4 pcf CERAFELT	0.20	27.0	3.13

HEATING5 Evaluations - 2000°F Temperature Pulse

Several materials were evaluated using the HEATING5 program and a 2000°F temperature pulse. The insulations were assumed to be in a doubled-sided configuration (Figure 1). Both single and composite materials were evaluated using this boundary condition.

Table 13 lists the evaluation results for both single materials and composites in order of increasing weight per square foot. One composite, 1/4-inch 8 pcf core lightweight flexible MIN-K plus 1/4-inch 4 pcf CERAFELT met the "modified" requirement on time to 400°F (8 minutes) and weighed less per square foot than 1-inch 4 pcf CERAFELT, the "baseline" material. The weight per square foot of this composite was 0.28 psf.

With one exception, all of the materials evaluated outperformed the 1-inch 4 pcf CERAFELT baseline requirement of eight minutes to 400°F. The exception was 1/4-inch CERAFORM 103 plus 1/2-inch 4 pcf CERAFELT, which allowed the aluminum plate to reach 400°F after only seven minutes into the simulation.

Isocyanurate foam was considered for use as part of a composite fire protection insulation. In all cases, the foam was considered to be on the "inside", adjacent to the aluminum plate, and therefore not directly exposed to the fire.

Isocyanurate foams in several thicknesses and with a variety of companion materials were evaluated using the HEATING5 program. The ASTM-E119 time-temperature curve was used and the double insulated configuration simulated. The foam was assumed to have a density of 3pcf, an apparent thermal conductivity ranging from 0.112 $\text{Btu}\cdot\text{in/hr}\cdot\text{ft}^2\cdot{}^{\circ}\text{F}$ at 50°F mean to 0.384 at 600°F mean temperature. Specific heat was assumed to be equivalent to that of freon, or 0.134 $\text{Btu/lb}\cdot{}^{\circ}\text{F}$ at 60°F mean to 0.162 at 440°F mean. Results from the evaluations are given in graphical form in Appendix E and in Table 14.

TABLE 13

HEATING5 EVALUATIONS - 2000°F TEMPERATURE PULSE

DOUBLE INSULATED CONFIGURATION

(Increasing psf Order)

Material Description	Weight Per Square Foot psf	Time to 400°F Min.	Temp. at 20 Min. °F
1/4-inch 8 pcf Core L.W. Flexible MIN-K + 1/4-inch 4 pcf CERAFELT	0.28	10.5	652
1-inch 4 pcf CERAFELT	0.33	8	881
1/4-inch, 13.5 pcf CERAFORM 103 + 1/2-in. 4 pcf CERAFELT	0.45	7	960
1-inch 6 pcf LO-CON	0.50	12	646
1-inch 6 pcf CERAFELT	0.50	10.5	682
1/4-inch 20 pcf MIN-K TE1400 + 1/4-in. 4.5 pcf MICROLITE B	0.51	15.5	493
1/4-inch 8 pcf L.W. Flexible MIN-K + 1-inch 4 pcf CERAFELT	0.53	20	400
3/8-inch 20 pcf MIN-K TE1400	0.62	30	293
1/1/4-inch 6 pcf Q-FIBER	0.62	13	583
1/4-inch 18.5 pcf CERAFORM 126 + 1/2-in. 6 pcf Q-FIBER	0.64	12	623
1/4-inch 18.5 pcf CERAFORM 126 + 1/2-inch 6 pcf LO-CON	0.64	10	768
3/4-inch 12 pcf THERMOFLEX II	0.75	10	733
1-1/2-inch 8 pcf KAOWOOL	1.0	15.5	521
2-inch 6 pcf CERAFIBER	1.0	14.5	542
1-inch 18.5 pcf CERAFORM 126	1.54	13	611

TABLE 14

HEATING 5 EVALUATIONS

COMPOSITE CONFIGURATIONS WITH 3 PCF ISOCYANURATE FOAM

ASTM-E119 TIME-TEMPERATURE CURVE/DOUBLE INSULATED CONFIGURATION

Hot Side Material	Hot Side Mat'l Thickness Inches	Foam Thickness Inches	Time to 450°F Min.	Temp. @ 30 Min. °F	*** TOXIC *** Time to 550°F, Min. Hot Side Foam	Midpoint Foam
Cerafelt, 4 pcf	0.50	1.00	55.0	250	4.5	7.0
Q-Fiber, 6 pcf	0.50	1.00	62.5	220	5.5	9.5
Q-Fiber, 6 pcf	0.50	0.50	42.0	324	6.0	10.0
Cerafelt, 4 pcf	0.50	0.50	34.5	390	4.5	8.0
Cerafelt, 4 pcf	0.50	0.25	25.5	542	5.0	9.0
Min-K TE1400	0.25	0.50	47.0	289	8.0	15.0
Flexible Min-K	0.25	0.50	38.0	367	4.0	8.5
Flexible Min-K	0.25	0.25	28.0	498	5.0	11.0

The tabulated results can be misleading if the only result considered is the minutes to 450°F of the aluminum plate. At about 550°F isocyanurate foam begins to char and disintegrate, losing its insulating capability. This fact could not be considered in the HEATING5 simulation. Therefore, although 1/2-inch 6 pcf Q-FIBER plus 1-inch foam appeared to have the best response to the ASTM-E119 curve (62.5 minutes for aluminum plate to reach 450°F), that would probably not be the real world case. A different composite, 1/4-inch MIN-K TE1400 plus 1/2-inch foam, although only rating 47 minutes for the plate to reach 450°F, may be superior in an actual fire. The MIN-K material prevented the foam hot side from reaching 450°F for 8 minutes compared to 5.5 minutes for the Q-FIBER. In the MIN-K simulation, the midpoint of the foam did not reach 550°F for 15 minutes, compared to 10 minutes for the Q-FIBER composite. Table 14 includes the times at which both the hot side and midpoint temperatures of the foam reach 550°F, which must be considered in addition to the time for the aluminum plate to reach 450°F.

Charring and loss of insulating capability are not the only factors necessary to consider. Toxic gases can be released when the foam begins to char and burn. An extensive study of foam in fire conditions would be necessary to determine the extent of danger to personnel when foam is used in fire proection applications.

Fire Testing

Small scale fire tests were conducted in the 2-foot by 2-foot furnace on several of the materials previously evaluated using the HEATING5 program. The ASTM-E119 time-temperature curve and the double insulated configuration were used in every case. Detailed results of the fire tests are located in Appendix D in tabular and graphic form.

Table 15 shows a summary of the fire test results as well as HEATING5 evaluation results for the same material and thickness, in increasing psf order. For the most part, fire test results were significantly better than results from the computer evaluation, though relative results between the materials were quite comparable. In a few cases, the HEATING5 results were better. The factors of binder burn-out, degree of edge heat loss, surface coefficients and temperature control in the fire tests all contribute to differences. Table 15 of results includes a quantitative demonstration of the last factor, temperature control, of the fire tests. The hot surface temperature of the material under consideration at 30 minutes is given in the table for both the fire test (average) and the HEATING5 evaluation. Whereas these hot surface temperatures are all within 15°F of each other for the HEATING5 evaluations, the range for the fire tests was about 450°F. This difference is greater than what would be accountable by performance differences between materials, and is probably due to temperature control considerations. Results from the small scale fire tests, therefore, are of limited value.

The baseline material, 1-inch 4 pcf CERAFELT, was fire-tested in the 2-foot by 2-foot furnace. The aluminum plate reached 450°F after 29.5 minutes, compared to 25.5 minutes using the HEATING5 program. The table summary of the data (Table 15) shows the fire test to have a significantly lower hot side temperature at 30 minutes than that of the HEATING5 evaluation also. The material having the best result during fire test was 1-inch 6pcf Q-FIBER, with a time of 56.5 minutes. The MIN-K materials also had good fire test results, with 50.5 minutes for 3/8-inch MIN-K 1301, 48.5 minutes for 3/8-inch MIN-K TE1400 and 42 minutes for 3/8-inch MIN-K 2000.

Intumescent Paint - A few refractory fiber materials were tested in the 2-foot by 2-foot furnace without and then with a coating of intumescent paint to help quantify the added benefit of such a coating. Ocean Chemicals, Inc. System 634/3342 was used. Detailed results in tabular and graphic form are located in Appendix D. A summary of the data is shown in Table 16.

TABLE 15

SMALL SCALE FIRE TEST RESULTS AND HEATING 5 EVALUATIONS

ASTM-E119 TIME TEMPERATURE CURVE/DOUBLE-SIDE INSULATED

(Increasing psf Order)

Material & Description	PSF	Small Scale Fire Test			Heating 5 Evaluation		
		Minutes to 450 °F	Temp. @ 30 Min. °F	Hot Side Temp. @ 30 Min. °F	Minutes to 450 °F	Temp. @ 30 Min. °F	Hot Side Temp. @ 30 Min. °F
1/2-inch, 6 pcf Q-Fiber	0.25	34	401	1438	17	790	1520
1-inch, 4 pcf Cerafelt	0.33	29.5	468	890	25.5	538	1529
3/8-inch, 10 pcf Core Flexible Min-K	0.35	28	482	1036	21	653	1526
1-inch, 6 pcf Q-Fiber	0.50	56.5	228	1482	27	502	1531
1-inch, 6 pcf Lo-Con	0.50	36	374	1346	33	405	1534
3/8-inch Min-K 1301	0.62	50.5	280	1264	56	258	1534
3/8-inch Min-K TE1400	0.62	48.5	286	1362	59	241	1535
3/8-inch Min-K 2000	0.62	42	332	1238	50	277	1532
1-inch, 8 pcf Kaowool	0.67	42.5	306	1259	26	525	1528
2-inch, 4 pcf Cerafelt	0.67	46	274	1457	31	436	1532
1-inch, 8 pcf Cerafelt	0.67	36	368	1478	27	524	1528
1-1/2-inch, 6 pcf Cerafiber	0.75	53.5	260	1435	28	490	1529
1-1/2-inch, 8 pcf Kaowool	1.00	37	176	1471	36.5	353	1534
1-inch Ceraform 126	1.54	40	336	1289	33	404	1528

TABLE 16

EFFECT OF INTUMESCENT PAINT ON FIRE PROTECTION ABILITY

SMALL SCALE FIRE TESTING - 2 FOOT by 2 FOOT FURNACE

Material & Description	Grams Primer on Hot Side	Grams Coating on Hot Side	Time to 450 ^{O}F Minutes	Temp. at 30 Min, ^{O}F	Hot Side Temp. at 30 Min, ^{O}F
CERAFELT - 1-inch 4 pcf					
No Coating	-	-	29	468	890
Intumescent Paint	37.7	66.2	31	434	1404
CERAFELT - 1-inch 8 pcf					
No Coating	-	-	36	368	1478
Intumescent Paint	38.0	61.8	39	345	1412
CERAFIBER - 1-1/2-inch 6 pcf					
No Coating	-	-	49	260	1463
Intumescent Paint	30.4	68.3	53.5	224	1435
CERAFELT - 2-inch 4 pcf					
No Coating	-	-	46	274	1457
Intumescent Paint	29.7	70.8	42.5	308	1144

In every case but one, that of 2-inch 4 pcf CERAFELT, the application of intumescent paint proved beneficial to the fire protection capability of the insulation system. The results from that particular test, however, as well as results from the 1-inch 4 pcf CERAFELT must be considered invalid. In the first case, the hot side control was erratic, dropping 150°F for no apparent reason between 15 and 20 minutes into the test; in the second case, comparison of the hot side temperatures at 30 minutes again shows evidence of poor temperature control.

The "time to 450°F" ratings of the other three materials were improved by 3 to 4.5 minutes with the addition of the intumescent paint coating, a gain of 8 to 9 percent. The weight per square foot added by the coating averaged 0.057 pounds, including one primer coat and two coats of the intumescent paint.

CONCLUSIONS AND RECOMMENDATIONS

From the study of various fire protection systems conducted under this contract, several conclusions can be drawn. Each conclusion is amplified in a summary discussion immediately following.

1. Better fire protection can be provided at a lower weight per foot squared than that of the system currently utilized.

2. The fire protection ability of a material or combination of materials can be approximated using a linear equation given physical property data on the material(s).

3. Foam insulation may provide good fire protection at a low weight per square foot, but should not be directly exposed to fire and thus must be used in combination with another material.

4. Adding an aluminum skin to the hot surface of a fire protection system does not contribute significantly to its protection ability, but does grossly increase its weight per square foot.

5. Intumescent paint applied to the outer surface of an insulation system can improve its fire protection capability for a slight increase in weight per square foot.

The computer study results showed that flexible MIN-K, whether used alone or in combination with another material, provides an alternative to the currently utilized system, 1-inch, 4 pcf CERAFELT with glass cloth facing. Flexible MIN-K (1/2-inch, 8 pcf core) simulated on HEATING5 allowed the aluminum plate to reach 450°F after 30.5 minutes compared to 25.5 minutes for the CERAFELT. The weight per foot squared of the MIN-K would be 0.40 psf compared to the 0.50 psf of the CERAFELT plus glass cloth. Other advantages of the MIN-K include better durability and rigidity, pre-applied and stitched glass cloth facing (easier installation), and lower thickness. The acoustical transmission loss properties of the Flexible MIN-K system would probably be better than the CERAFELT, thus making it a more effective sound barrier. The CERAFELT however, would prove more effective as a sound "muffler" within an enclosure having better sound absorption properties. The 1-inch 4 pcf CERAFELT would provide better room temperature thermal protection with an R-value of 3.6 than the MIN-K/CERAFELT combination (R-value 2.4) or the MIN-K alone (R-value 2.9).

The flexible MIN-K is more expensive than the CERAFELT. A combination of flexible MIN-K (1/4-inch, 8 pcf core) and 4 pcf CERAFELT (1/4-inch) thus may be more desirable since less MIN-K and therefore less cost is involved. Results from this system were almost equivalent to CERAFELT's, at 25 minutes, but this composite weighs only 0.28 psf, and has the same advantages as 1/2-inch flexible MIN-K.

The following equations are recommended for use in approximating the fire protection capability (aluminum plate response) of different materials or combinations.

Equation 1. For refractory fiber, double insulated configuration, ASTM-E119 time-temperature curve:

$$\text{Minutes to } 450^{\circ}\text{F} = 35.83 - 2.37\left(C\rho \times \frac{C}{\rho c_p}\right)$$

95 percent confidence ± 1.8 minutes

90 percent confidence ± 1.5 minutes

Where:

C = Thermal conductance at 1000°F, Btu/hr·ft^2·°F
ρ = Density, pcf
c_p = Specific heat at 1000°F, Btu/lb°F

Equation 2. For opacified particulate, double insulated configuration, ASTM-E119 time-temperature curve:

$$\text{Minutes to } 450^{\circ}F = 84.78 - 222.84 \frac{C}{\rho c_p}$$

95 percent confidence ±8.5 minutes
90 percent confidence ±6.7 minutes

Equation 3. For material composites, double insulated configuration, ASTM-E119 time-temperature curve:

$$\text{Minutes to } 450^{\circ}F = 42.49 - 0.0736 (C\rho)_1 (C\rho)_2 \left(\frac{C}{\rho c_p}\right)_1$$

95 percent confidence ±4.7 minutes
90 percent confidence ±3.6 minutes

Where:

Subscript 1 refers to the outer or hot side material. Subscript 2 refers to the inner or cold side material.

These equations are useful to give a prediction of the response of a material relative to that of a known material.

Isocyanurate foam used in a composite with other fire protection materials is a very attractive option due to its lightweight and excellent thermal characteristics. It is recommended that more study be put into foams, including the newer fire-retardant polyimide foams developed by International Harvester/Solar Turbine Division. (Information on these foams did not arrive in time for analysis and inclusion in this report.) Research into the toxicity and deterioration of foam at high temperatures is recommended. In conjunction, developmental work on obtaining an acceptable composite utilizing foam is recommended.

An aluminum skin surface added little to the fire protection ability of a material, but significantly to the weight per square foot. It is not recommended for use on Navy bulkheads.

An intumescent paint coating on the hot surface of an insulation contributed up to 4.5 minutes to the fire protection rating (8 to 9 percent) of a material in a small scale fire test at an average added weight per square foot of 0.057 psf. It is recommended that intumescent paint be used as a surface coating regardless of the material selected for fire protection. This step could be taken immediately on the existing Navy bulkhead fire protection systems.

RECOMMENDATIONS

Based on the above conclusions, it is recommended that:

1. Large scale laboratory fire tests be conducted on the Flexible MIN-K (1/2-inch, 8 pcf core) product, and the Flexible MIN-K (1/4-inch, 8 pcf core) and 4 pcf CERAFELT (1/4-inch) system in conjunction with the 4 pcf CERAFELT (1-inch) standard to confirm the HEATING5 results. Large scale fire tests on Q-Fiber and Lo-Con would also provide helpful information.

2. If the large scale laboratory fire tests confirm the HEATING5 advantages, a program be initiated to establish the techniques to combine the materials (Flexible MIN-K and CERAFELT) into a single product, to apply it to the various bulkhead and structural configurations, and to evaluate the cost effectiveness of the new system.

3. Consideration be given to a program to improve the thermal performance of existing refractory fiber products through the introduction of opacifiers.

4. An intumescent paint system equivalent to the Ocean Chemicals, Inc., System 63/3342 be

incorporated into the full scale laboratory fire tests to confirm the findings of the small scale fire tests.

5. The equations developed to describe the thermal response of the aluminum bulkhead be utilized to generate comparisons between known materials and new materials, or to establish the necessary properties of a material for a certain degree of protection.

APPENDIX A

APPENDIX A

LIST OF MANUFACTURERS

	Manufacturer and Address	Material Produced
1.	Babcock International, Ltd. Cleveland House St. James's Square London SW1Y 4LN England Telephone: 01-930-9766	KAOWOOL
2.	Carborundum Company (Subsidiary: Kennecott Copper Corporation) Carborundum Center Niagara Falls, New York 14302 Telephone: (716) 278-2000	Fiberfrax LO-CON
3.	A. P. Green Refractories Company (Subsidiary: U. S. Gypsum Co.) Green Boulevard Mexico, Missouri 65265 Telephone: (314) 473-3626	INSWOOL HP
4.	ICI Americas, Incorporated (Subsidiary: Imperial Chemical Industries, Limited) New Murphy and Concord Pike Wilmington, Delaware 19897 Telephone: (302) 575-3000	SAFFIL Fiber
5.	Johns-Manville Corporation P. O. Box 5108 Denver, Colorado 80217 Telephone: (303) 978-2000	CERAFELT, CERABLANKET Flexible MIN-K, Rigid MIN-K, CERAFORM THERMOFLEX II, Q-FIBER CERACHROME, Unbonded MICROLITE B

APPENDIX B

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity Btu·in/hr·ft²·°F Mean °F	K_a	Specific Heat, Btu/°F·lb Mean °F	Cp
Johns-Manville CERAFELT (Sales Literature IND 3075)	3	1/4"-3"	600	0.70	200	0.20
			1000	1.25	400	0.22
			1400	1.95	600	0.23
			1600	2.45	800	0.24
			2000	3.80	1000	0.25
					1200	0.26
					1400	0.27
	4	1/4"-2"	600	0.60	Same as Above	
			1000	1.08		
			1400	1.70		
			1600	2.08		
			2000	3.10		
	6	1/4"-1-1/2"	600	0.55	Same as Above	
			1000	0.80		
			1400	1.25		
			1600	1.58		
			2000	2.30		
	8	1/4"-1-1/2"	600	0.51	Same as Above	
			1000	0.75		
			1400	1.08		
			1600	1.30		
			2000	1.90		
	10	1/4"-1"	600	0.50	Same as Above	
			1000	0.70		
			1400	0.90		
			1600	1.10		
			2000	1.62		

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity $Btu \cdot in/hr \cdot ft^2 \cdot {}^oF$ Mean ^oF	K_a	Specific Heat, $Btu/{}^oF \cdot lb$ Mean ^oF	Cp
Johns-Manville CERABLANKET (Sales Lit. IND-247)	3	1/2"-1-1/2"	600	0.79	Same as CERAFELT	
			800	1.05		
			1000	1.40		
			1200	1.80		
	4	1/2"-1-1/2"	600	0.75	Same as Above	
			800	0.95		
			1000	1.20		
			1200	1.55		
	6	1/4"-1-1/2"	600	0.62	Same as Above	
			800	0.82		
			1000	1.00		
			1200	1.26		
	8	1/4"-1"	600	0.55	Same as Above	
			800	0.78		
			1000	0.92		
			1200	1.12		
Johns-Manville Lightweight Flexible MIN-K (Sales Lit. AI-15)	Core - 8 pcf		100	0.19	200	0.20
	0.20 psf	1/4"	200	0.21	400	0.22
	0.28 psf	3/8"	400	0.27	800	0.25
			600	0.33	1200	0.27
			800	0.38	1600	0.28
	Core - 10 pcf		100	0.18	Same as Above	
	0.24 psf	1/4"	200	0.20		
	0.35 psf	3/8"	400	0.25		
			600	0.29		
			800	0.35		

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity Btu·in/hr·ft^2·^oF Mean ^oF	K_a	Specific Heat, Btu/^oF·lb Mean ^oF	Cp
Johns-Manville Standard Flexible MIN-K (Sales Lit. AI-15)	Core - 16 pcf 0.21 psf	1/8"	400	0.27	Same as Above	
			600	0.29		
			800	0.32		
			1000	0.36		
			1200	0.41		
			1400	0.47		
			1600	0.56		
	Core - 16 pcf 0.29 psf	3/16"	400	0.25	Same as Above	
			600	0.27		
			800	0.30		
			1000	0.33		
			1200	0.37		
			1400	0.44		
			1600	0.53		
	Core - 16 pcf 0.38 psf	1/4"	400	0.24		
			600	0.26		
			800	0.28		
			1000	0.32		
			1200	0.37		
			1400	0.43		
			1600	0.51		
	Core - 16 pcf 0.54 psf	3/8"	400	0.23	Same as Above	
			600	0.25		
			800	0.28		
			1000	0.31		
			1200	0.35		
			1400	0.41		
			1600	0.50		

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity Btu·in/hr·ft^2·°F Mean °F	K_a	Specific Heat, Btu/°F·lb Mean °F	Cp
Johns-Manville Mid-Range Flexible MIN-K (Sales Lit. AI-15)	Core - 16 pcf	1/8"	75	0.22	Same as Above	
			300	0.26		
			500	0.31		
			800	0.35		
			1000	0.39		
	Core - 16 pcf	3/16"	75	0.22	Same as Above	
			300	0.24		
			500	0.27		
			800	0.32		
			1000	0.37		
	Core - 16 pcf	1/4"	75	0.21	Same as Above	
			300	0.24		
			500	0.26		
			800	0.31		
			1000	0.36		
	Core - 16 pcf	3/8"	75	0.21	Same as Above	
			300	0.24		
			500	0.26		
			800	0.31		
			1000	0.36		

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity Btu·in/hr·ft²·°F Mean °F	K_a	Specific Heat, Btu/°F·lb Mean °F	Cp
Johns-Manville High Temperature Flexible MIN-K (Sales Lit. AI-15)	Core - 16 pcf 0.27 psf	1/8"	400	0.27	Same as Above	
			600	0.29		
			800	0.32		
			1000	0.36		
			1200	0.41		
			1400	0.47		
			1600	0.56		
	Core - 16 pcf 0.36 psf	3/16"	400	0.25	Same as Above	
			600	0.27		
			800	0.30		
			1000	0.33		
			1200	0.37		
			1400	0.44		
			1600	0.53		
	Core - 16 pcf 0.44 psf	1/4"	400	0.24	Same as Above	
			600	0.26		
			800	0.28		
			1000	0.32		
			1200	0.37		
			1400	0.43		
			1600	0.51		
	Core - 16 pcf 0.61 psf	3/8"	400	0.23	Same as Above	
			600	0.25		
			800	0.28		
			1000	0.31		
			1200	0.35		
			1400	0.41		
			1600	0.50		

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity Btu·in/hr·ft^2·°F Mean °F	K_a	Specific Heat, Btu/°F·lb Mean °F	C_p
Johns-Manville CERAFORM 102 (Merch. Bulletin 79A-35-3)	24	1/8"-1/2"	400	0.25	200	0.20
			800	0.33	400	0.22
			1200	0.82	600	0.23
			1600	1.10	800	0.24
			2000	1.53	1000	0.25
					1200	0.26
					1400	0.27
Johns-Manville CERAFORM 106R (Sales Lit. IND-301)	24	1/8"-1"	500	0.54	Same as Above	
			800	0.75		
			1000	0.89		
			1200	1.05		
Johns-Manville CERAFORM 103 (Sales Lit. IND-301)	13.5	1/4"-1"	400	0.28	Same as Above	
			800	0.39		
			1200	0.93		
			1600	1.36		
			2000	1.98		
Johns-Manville CERAFORM 126 (Sales Lit. IND-301)	18.5	1/4"-1"	400	0.27	Same as Above	
			800	0.36		
			1200	0.88		
			1600	1.20		
			2000	1.66		

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity Btu·in/hr·ft^2·^oF Mean ^oF	K_a	Specific Heat, Btu/^oF·lb Mean ^oF	Cp
Johns-Manville CERAFORM 141 (Sales Lit. IND-301)	13.5	1/4"-1"	400	0.28	Same as Above	
			800	0.39		
			1200	0.93		
			1600	1.36		
			2000	1.98		
Johns-Manville CERAFORM 130 (Sales Lit. IND-301)	13.5	1/4"-1"	400	0.28	Same as Above	
			800	0.39		
			1200	0.93		
			1600	1.36		
			2000	1.98		
Johns-Manville CERAFORM 143 (Sales Lit. IND-301)	22	1/4"-1"	400	0.62	Same as Above	
			800	0.67		
			1200	0.86		
			1600	1.14		
			2000	1.50		
ICI Americas SAFFIL Fiber Mat (Sales Lit. 821-1)	6	1-1/2"	400	0.55	0.25	
			800	0.70		
			1200	0.90		
			1600	1.30		
			2000	1.80		
			2400	2.45		

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity Btu·in/hr·ft^2·°F Mean °F	K_a	Specific Heat, Btu/°F·lb Mean °F	Cp
Johns-Manville THERMOFLEX II (Sales Lit. FG-515)	3	1/2"-1"	600	0.82	200	0.20
			800	1.10	400	0.22
			1000	1.46	600	0.23
			1200	1.90	800	0.24
			1400	2.50	1000	0.25
			1600	3.15	1200	0.26
			1800	3.90	1400	0.27
			2000	4.90		
	4	1/4"-1"	600	0.75	Same as Above	
			800	0.95		
			1000	1.25		
			1200	1.62		
			1400	2.06		
			1600	2.58		
			1800	3.20		
			2000	3.94		

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity $Btu \cdot in/hr \cdot ft^2 \cdot {}^oF$ Mean ^oF	K_a	Specific Heat, $Btu/{}^oF \cdot lb$ Mean ^oF	C_p
Johns-Manville THERMOFLEX II (Continued)	6	1/4"-1"	600	0.65	Same as Above	
			800	0.85		
			1000	1.05		
			1200	1.30		
			1400	1.65		
			1600	2.00		
			1800	2.40		
			2000	2.90		
	8	1/8"-1"	600	0.55	Same as Above	
			800	0.72		
			1000	0.88		
			1200	1.05		
			1400	1.30		
			1600	1.65		
			1800	2.00		
			2000	2.40		
	12	1/8"-1"	600	0.51	Same as Above	
			800	0.65		
			1000	0.79		
			1200	0.91		
			1400	1.11		
			1600	1.38		
			1800	1.63		
			2000	1.94		

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity Btu·in/hr·ft^2·^{o}F: Mean ^{o}F	K_a	Specific Heat, Btu/^{o}F·lb: Mean ^{o}F	C_p
Johns-Manville Q-FIBER FELT (Sales Lit. AI-8)	3	1/8"-1"	300	0.36	200	0.20
			400	0.43	400	0.23
			500	0.50	600	0.25
			600	0.57	800	0.26
			700	0.65	1000	0.27
			800	0.73	1200	0.28
			900	0.82	1400	0.28
			1000	0.91	1600	0.29
	3.5	1/8"-1"	300	0.33	Same as Above	
			400	0.39		
			500	0.46		
			600	0.53		
			700	0.60		
			800	0.67		
			900	0.75		
			1000	0.83		
	6	1/8"-1"	75	0.23	Same as Above	
			300	0.30		
			400	0.34		
			500	0.39		
			600	0.44		
			700	0.50		
			800	0.56		
			900	0.62		
			1000	0.68		

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity Btu·in/hr·ft^2·°F Mean °F	K_a	Specific Heat, Btu/°F·lb Mean °F	C_p
Johns-Manville CERACHROME (Sales Lit. AI-2)	6	Variable	600	0.60	200	0.20
			1000	0.90	1000	0.25
			1400	1.35	1800	0.27
			2000	2.30		
	8	Variable	600	0.59	Same as Above	
			1000	0.80		
			1400	1.15		
			2000	1.88		
	10	Variable	600	0.55	Same as Above	
			1000	0.75		
			1400	1.00		
			2000	1.65		
Johns-Manville Unbonded MICROLITE B (Sales Lit. AI-4)	1.5	1/4"	75	0.23	200	0.20
			100	0.24	400	0.22
			200	0.31	600	0.23
			300	0.39	800	0.24
			400	0.48	1000	0.25
			500	0.59	1200	0.26
			600	0.71	1400	0.27
			700	0.86		
			800	1.03		

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity Btu·in/hr·ft^2·^{o}F Mean ^{o}F	K_a	Specific Heat, Btu/^{o}F·lb Mean ^{o}F C_p
Johns-Manville Unbonded MICROLITE B (Continued)	3.0	1.4"	75	0.21	Same as Above
			100	0.22	
			200	0.26	
			300	0.32	
			400	0.39	
			500	0.46	
			600	0.54	
			700	0.62	
			800	0.72	
	4.5	1/4"	75	0.21	Same as Above
			100	0.21	
			200	0.25	
			300	0.29	
			400	0.34	
			500	0.39	
			600	0.45	
			700	0.51	
			800	0.59	
Carborundum Fiberfrax LO-CON (sales Lit. A2303-1)	4	1/4"-1-1/2"	400	0.39	Same as Above
			800	0.70	
			1200	1.13	
			1600	1.69	
			2000	2.50	
	6	1/4"-1-1/2"	400	0.34	Same as Above
			800	0.61	
			1200	0.98	
			1600	1.48	
			2000	1.98	

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity $Btu \cdot in/hr \cdot ft^2 \cdot {}^oF$ Mean ^oF	K_a	Specific Heat, $Btu/{}^oF \cdot lb$ Mean ^oF Cp
Babcock & Wilcox KAOWOOL (Sales Lit. No. 115)	3	1/2"-2"	400	0.40	Same as Above
			800	0.88	
			1200	1.55	
			1600	2.38	
			1800	2.80	
	4	1/2"-2"	400	0.34	Same as Above
			800	0.72	
			1200	1.27	
			1600	1.90	
			1800	2.23	
	6	1/4"-1-1/2"	400	0.30	
			800	0.62	
			1200	1.07	
			1600	1.59	
			1800	1.83	
	8	1/4"-1-1/2"	400	0.28	Same as Above
			800	0.53	
			1200	0.90	
			1600	1.32	
			1800	1.55	
A.P. Green INSWOOL-HP (SalesLit. 1/MI-107908)	4	Variable	600	0.50	Same as Above
			1000	0.90	
			1400	1.60	
			1600	1.90	

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity Btu·in/hr·ft^2·^{o}F Mean ^{o}F	K_a	Specific Heat, Btu/^{o}F·lb Mean ^{o}F	C_p
A. P. Green INSWOOL-HP (Continued)	6	-	600	0.50	Same as Above	
			1000	0.90		
			1400	1.40		
			1600	1.70		
	8	-	600	0.40	Same as Above	
			1000	0.80		
			1400	1.10		
			1600	1.30		
Johns-Manville MIN-K 1301	20	3/8"-3"	100	0.19	400	0.23
			300	0.21	800	0.25
			400	0.22	1200	0.27
			600	0.23	1600	0.27
			800	0.25		
			1000	0.27		
			1400	0.31		
			2000	0.37		
Johns-Manville MIN-K 2000 (Sales Lit. AI-15)	20	3/8"-3"	100	0.22	Same as Above	
			500	0.24		
			800	0.27		
			1000	0.30		
			1200	0.34		
			1400	0.39		
			1600	0.46		
			1800	0.55		

APPENDIX B

MATERIAL PROPERTIES TABULATION

Material Name	Density, PCF	Thicknesses Available Inches	Apparent Thermal Conductivity Btu·in/hr·ft^2·°F Mean °F	K_a	Specific Heat, Btu/°F·lb Mean °F	C_p
Johns-Manville MIN-K TE1400 (Sales Lit. AI-15)	20	3/8"-3"	100	0.16	Same as Above	
			400	0.19		
			600	0.21		
			800	0.23		
			1000	0.25		
			1200	0.27		
			1600	0.32		
			2000	0.37		
Isocyanurate Foam	3	1/4"+	50	0.112	60	0.134
			60	0.114	100	0.139
			80	0.123	200	0.148
			100	0.134	300	0.155
			120	0.144	440	0.162
			400	0.284		
			600	0.384		

APPENDIX C

APPENDIX C

Table 1 of Results

HEATING5 EVALUATIONS - ASTM-E119 TIME-TEMPERATURE CURVE

DOUBLE INSULATED CONFIGURATION

Material & Description	PSF	Aluminum Plate Temperature at Time, Minutes									
		0	5	10	15	20	30	40	60	80	120
CERAFELT - 1-inch, 4 pcf	0.33	68	84	151	245	344	538	718	998	1168	1323
CERAFIBER - 1-1/2-inch 6 pcf	0.75	68	74	124	210	304	490	657	-	1083	1248
CERAFELT - 1-inch, 8 pcf	0.67	68	79	141	234	332	524	696	-	1120	1278
Flexible MIN-K - 3/8-inch 10 pcf core	0.35	68	95	199	325	445	653	812	-	1117	1220
Flexible MIN-K - 1/2-inch 8 pcf core	0.40	68	83	146	222	299	442	568		880	1014
CERAFELT - 2-inch, 4 pcf	0.67	68	73	114	186	268	436	599	-	1066	1269
CERAFIBER - 2-inch, 6 pcf	1.0	68	71	100	158	227	372	513	-	950	1180
KAOWOOL - 1-1/2-inch, 8 pcf	1.0	68	69	90	142	209	353	494	-	939	1177
INSWOOL - 1-1/4-inch, 8 pcf	0.83	68	73	117	192	275	440	589	-	989	1163
LO-CON - 1-1/2-inch, 6 pcf	0.75	68	71	106	174	251	410	562	-	1003	1220
SAFFIL - 1-1/2-inch, 6 pcf	0.75	68	71	103	163	232	374	512	-	938	1168
THERMOFLEX II - 1/2-inch 12 pcf	0.50	68	129	374	649	857	1076	1167	-	1315	1391
CERAFORM 126 - 1-inch 18.5 pcf	1.54	68	70	97	157	236	404	565	-	1024	1232
Q-FIBER - 1-inch, 6 pcf	0.50	68	80	143	231	324	502	661	-	1060	1219
Q-FIBER - 1-1/4-inch 6 pcf	0.63	68	75	118	186	262	414	556	-	969	1172

APPENDIX C (Continued)
Table 1 of Results

Material & Description	PSF	Aluminum Plate Temperature at Time, Minutes									
		0	5	10	15	20	30	40	60	80	120
MICROLITE B - 1-1/2-inch 4.5 pcf	0.56	68	72	112	180	256	412	563	-	1006	1216
MIN-K 1301 - 3/4-inch 20 pcf	1.25	68	69	76	94	121	188	258	-	517	724
MIN-K 2000 - 1-inch, 20 pcf	1.67	68	69	74	86	104	148	201	-	427	637
MIN-K TE1400 - 1/2-inch 20 pcf	0.83	68	72	95	135	182	280	375	-	694	909
MIN-K 1301 - 3/8-inch 20 pcf	0.63	68	73	99	137	177	258	337	-	616	824
MIN-K 2000 - 3/8-inch, 20 pcf	0.63	68	74	103	143	187	277	365	-	680	917
MIN-K TE1400 - 3/8-inch, 20 pcf	0.63	68	72	95	128	165	241	317	-	594	807
CERAFORM 126 - 1/4-inch, 18.5 pcf Plus Q-FIBER, 1/2-inch, 6 pcf	0.64	68	71	107	186	274	448	608	-	1017	1181
Flexible MIN-K - 1/4-in., 8 pcf core plus CERAFELT 1/4-inch, 4 pcf	0.28	68	94	181	278	371	537	676	-	980	1084
CERAFORM 126 - 1/4-inch, 18.5 pcf plus LO-CON 1/2-inch, 6 pcf	0.64	68	73	112	195	288	479	659	-	1135	1322
MIN-K TE1400 - 1/4-inch 20 pcf, plus MICROLITE B 1/4-inch, 4.5 pcf	0.51	68	72	112	175	243	379	506	-	865	1040
Flexible MIN-K - 1/4-In. 8 pcf core plus CERAFELT 1-inch, 4 pcf	0.53	68	74	109	160	214	324	432	-	798	1027

APPENDIX C (Continued)
Table 1 of Results

Material & Description	PSF	Aluminum Plate Temperature at Time, Minutes 0	5	10	15	20	30	40	60	80	120
CERAFORM 126 - 1/2-inch 18.5 pcf plus AIR-GAP, 1/4-inch	0.77	68	73	110	189	279	477	679	-	1203	1354
THERMOFLEX II - 3/4-in. 12 pcf	0.75	68	77	133	217	306	479	638	-	1066	1249
CERAFORM 103 - 1-inch 13.5 pcf	1.13	68	68	77	105	154	277	412	-	920	1233
THERMOFLEX II - 1/2-in., 12 pcf plus AIR GAP, 1/2-inch	0.50	68	90	183	303	421	537	815	-	1175	1298
KAOWOOL - 1-in., 8 pcf	0.75	68	76	136	230	330	526	700	-	1117	1266
Q-FIBER - 1/2-in., 6 pcf	0.25	68	105	241	402	552	790	949	-	1193	-
CERAFORM 103 - 1/4-inch 13.5 pcf plus CERAFELT 1/2-inch, 4 pcf	0.45	68	80	147	252	364	583	782	-	1069	1365
LO-CON - 1-inch, 6 pcf	0.50	68	79	154	261	373	583	762	-	1147	1273
CERAFELT - 1/2-inch, 4 pcf, FOAM - 1-inch, 3 pcf	0.42	68	69	90	127	167	250	333	487	619	814
Q-FIBER - 1/2-inch, 6 pcf, FOAM - 1-inch, 3 pcf	0.50	68	68	82	113	147	220	292	431	554	747
Q-FIBER - 1/2-inch, 6 pcf, FOAM - 1/2-in. 3 pcf	0.38	68	71	105	157	213	324	430	610	749	934
CERAFELT - 1/2-inch, 4 pcf, FOAM - 1/2-inch, 3 pcf	0.30	68	75	122	187	256	390	514	711	851	1025
CERAFELT - 1/2-inch, 4 pcf, FOAM - 1/4-inch 3 pcf	0.23	68	83	156	255	356	542	693	905	1039	1183

APPENDIX C (Continued)
Table 1 of Results

Material & Description	PSF	Aluminum Plate Temperature at Time, Minutes									
		0	5	10	15	20	30	40	60	80	120
MIN-K TE1400 - 1/4-inch 20 pcf, FOAM - 1/2-inch 3 pcf	0.54	68	69	92	136	186	289	389	566	705	896
Flexible MIN-K, 1/4-inch 8 pcf core, FOAM - 1/2-inch, 3 pcf	0.33	68	77	122	181	243	367	482	672	811	986
Flexible MIN-K, 1/4-inch 8 pcf core, FOAM - 1/4-inch, 3 pcf	0.26	68	85	153	239	327	493	634	838	970	1113
CERAFELT - 1-inch, 4 pcf, Aluminum - 0.1 inch, 168.5 pcf	1.74	68	74	130	224	324	519	702	988	1163	1321
CERAFELT - 1-inch, 4 pcf, Aluminum - 0.05 inch, 168.5 pcf	1.04	68	77	140	234	333	528	710	993	1165	1322
CERAFELT - 1-inch, 4 pcf, Aluminum - 0.20 inch, 168.5 pcf	3.14	68	72	114	205	305	503	688	979	1157	1320

APPENDIX C

Table 2 of Results

HEATING5 EVALUATIONS - ASTM-E119 TIME-TEMPERATURE CURVE

SINGLE INSULATED CONFIGURATION

Material & Description	PSF	Aluminum Plate Temperature at Time, Minutes								
		0	5	10	15	20	30	40	80	120
CERAFELT - 1-inch, 4 pcf	0.33	68	84	145	206	251	304	333	384	411
CERAFIBER - 1-1/2-in., 6 pcf	0.75	68	73	117	178	226	285	315	366	391
CERAFELT - 1-inch, 8 pcf	0.67	68	79	131	194	242	300	330	383	411
Flexible MIN-K - 3/8-inch 10 pcf core	0.35	68	93	177	253	304	358	385	431	455
Flexible MIN-K - 1/2-inch 8 pcf core	0.40	68	93	162	221	262	307	329	366	385
CERAFELT - 2-inch, 4 pcf	0.67	68	71	103	155	198	254	284	335	360
CERAFIBER - 2-inch, 6 pcf	1.0	68	71	97	140	179	232	261	307	330
KAOWOOL - 1-1/2-in., 8 pcf	1.0	68	69	88	128	168	223	253	300	322
INSWOOL - 1-1/4-in., 8 pcf	0.83	68	73	111	164	207	260	287	329	349
LO-CON - 1-1/2-inch, 6 pcf	0.75	68	71	101	150	192	244	272	319	342
SAFFIL - 1-1/2-in., 6 pcf	0.75	68	71	99	143	182	232	259	303	325
THERMOFLEX II - 1/2-inch, 12 pcf	0.50	68	127	334	507	595	669	708	794	841
CERAFORM 126 - 1-in, 18.5 pcf	1.54	68	70	95	144	194	264	301	358	385
Q-FIBER - 1-inch, 6 pcf	0.50	68	79	131	188	230	281	308	352	375
Q-FIBER - 1-1/4-inch, 6 pcf	0.63	68	74	111	157	195	242	267	309	330
MICROLITE_B - 1-1/2-inch 4.5 pcf	0.56	68	72	106	152	190	239	266	311	333
MIN-K 1301 - 3/4-inch, 20 pcf	1.25	68	69	75	90	108	140	160	189	199
MIN-K 2000- 1-inch, 20 pcf	1.67	68	69	74	84	95	119	137	172	186
MIN-K TE1400 - 1/2-inch, 20 pcf	0.83	68	71	92	121	147	182	201	230	243

APPENDIX C

Table 3 of Results

HEATING5 EVALUATIONS - 2000°F TEMPERATURE PULSE

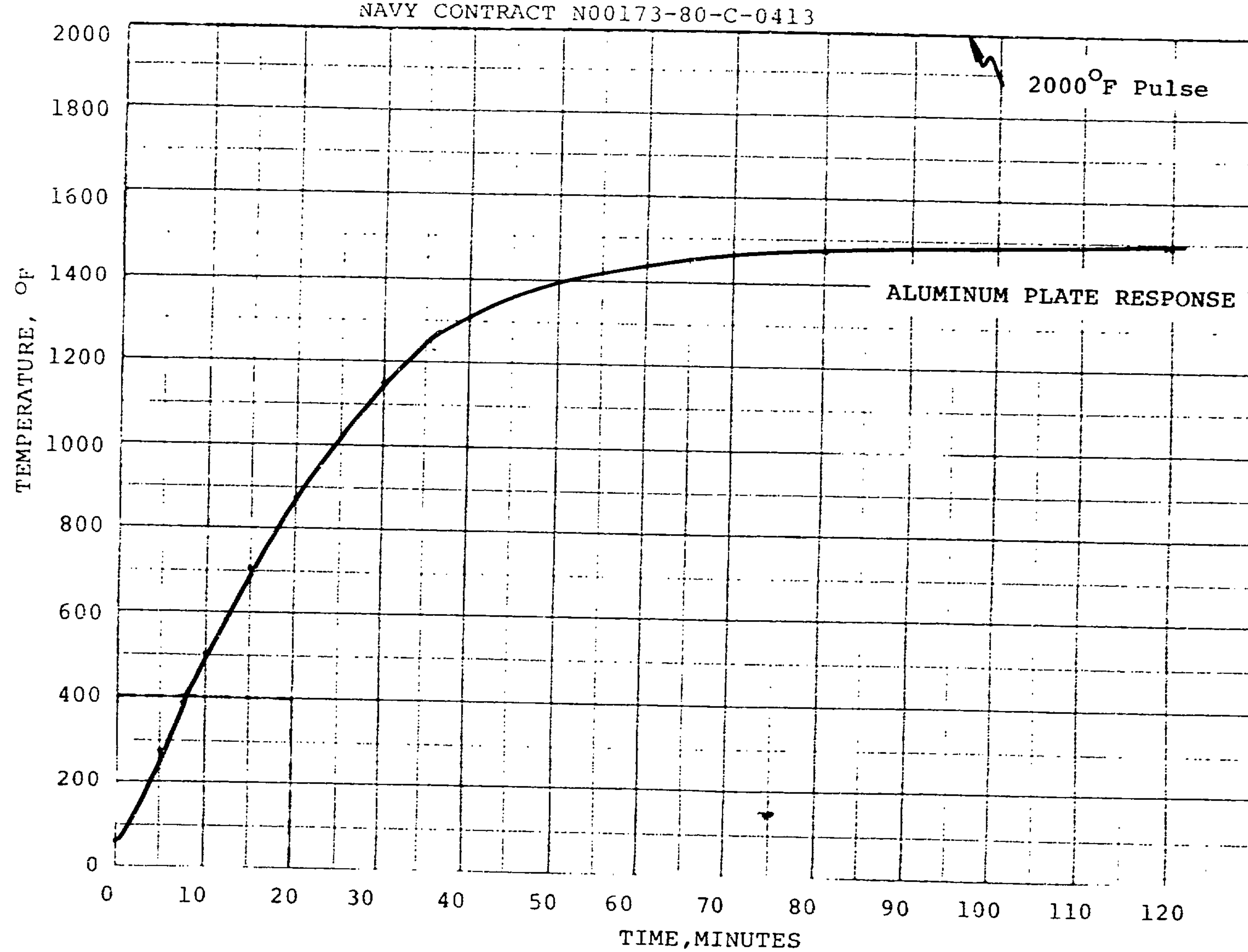
DOUBLE INSULATED CONFIGURATION

Material & Description	PSF	Aluminum Plate Temperature at Time, Minutes								
		0	5	10	15	20	30	40	80	120
CERAFELT - 1-inch, 4 pcf	0.33	68	276	503	706	881	1144	1304	1478	1489
MIN-K TE1400 - 3/8-inch 20 pcf	0.63	68	109	172	234	293	404	503	808	997
Q-FIBER - 1-1/4-inch 6 pcf	0.63	68	170	320	458	583	794	957	1280	1360
CERAFORM 126 - 1-inch 18.5 pcf	1.54	68	142	304	466	611	852	1033	1356	1419
KAOWOOL - 1-1/2-inch 8 pcf	1.0	68	122	259	396	521	738	913	1283	1385
CERAFORM 126 - 1/4-inch, 18.5 pcf plus Q-FIBER - 1/2-inch, 6 pcf	0.64	68	178	343	491	624	838	993	1268	1335
Flexible MIN-K - 1/4-inch 8 pcf core plus CERAFELT 1/4-inch, 4 pcf	0.28	68	232	391	530	652	843	972	1164	1193
MIN-K TE1400 - 1/4-inch 20 pcf plus MICROLITE B 1/4-inch, 4.5 pcf	0.51	68	141	268	386	493	674	814	1109	1205
CERAFELT - 1-inch, 6 pcf	0.50	68	199	377	537	682	922	1102	1409	1459
THERMOFLEX II - 3/4-inch 12 pcf	0.50	68	202	401	578	733	978	1147	1404	1439
CERAFIBER - 2-inch, 6 pcf	1.0	68	141	281	417	543	759	931	1290	1385
Flexible MIN-K - 1/4-inch 8 pcf core plus CERAFELT 1-inch, 4 pcf	0.53	68	124	222	314	401	560	701	1063	1201
CERAFORM 126 - 1/4-inch, 18.5 pcf plus LO-CON 1/2-inch, 6 pcf	0.64	68	208	415	602	768	1032	1214	1466	1491
CERAFORM 103 - 1/4-inch 13.5 pcf plus CERAFELT 1/2-inch, 4 pcf	0.45	68	293	548	772	960	1227	1378	1488	1516
LO-CON - 1-inch, 6 pcf	0.50	68	176	345	502	646	890	1076	1402	1458

APPENDIX C

GRAPH OF RESULTS
DOUBLE INSULATED CONFIGURATION
HEATING 5 EVALUATION - **CERAFELT -- 1 inch, 4pcf**

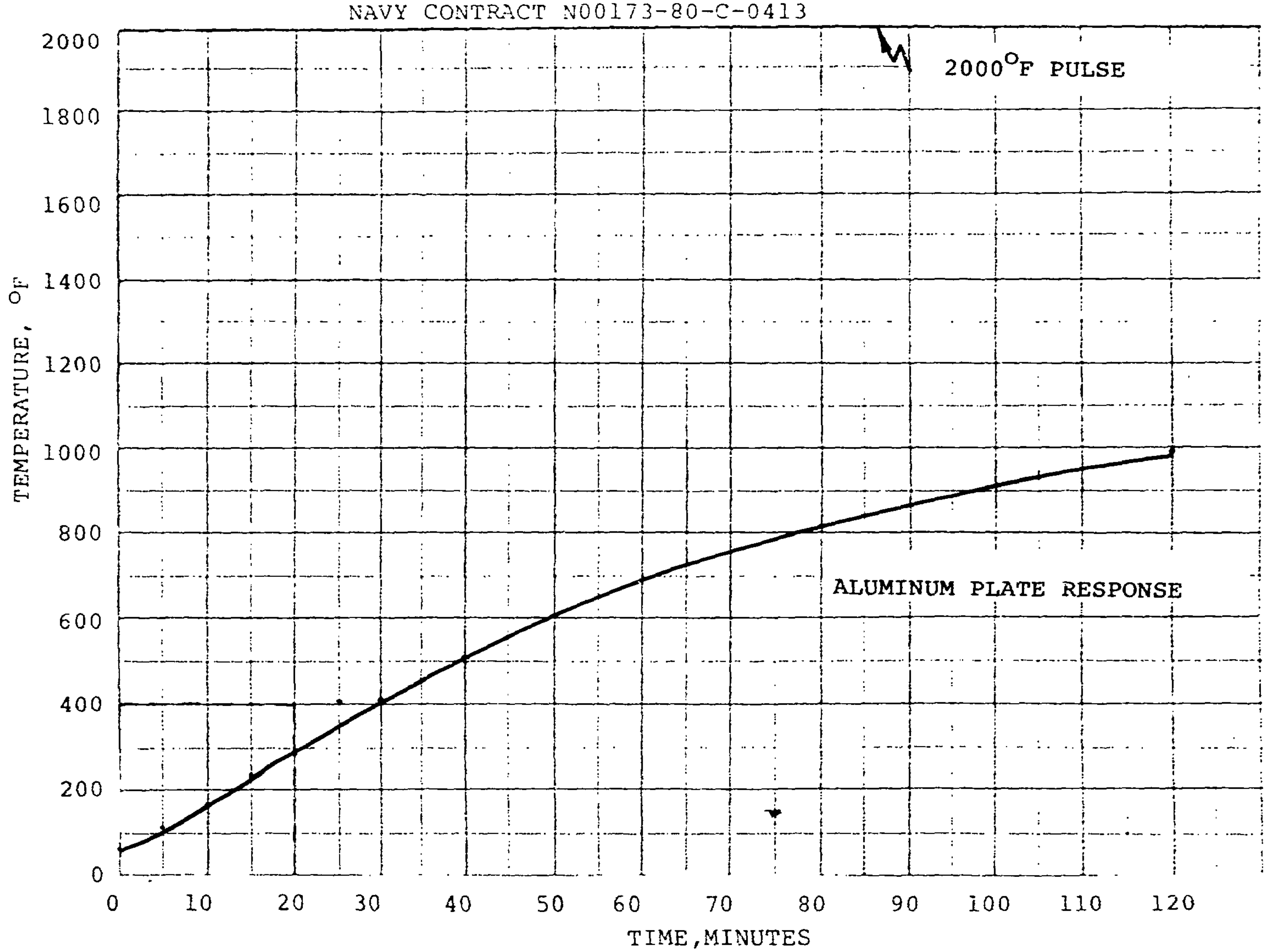
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS
DOUBLE INSULATED CONFIGURATION
HEATING 5 EVALUATION - **MIN-K TE1400 -- 3/8 inch, 20pcf**

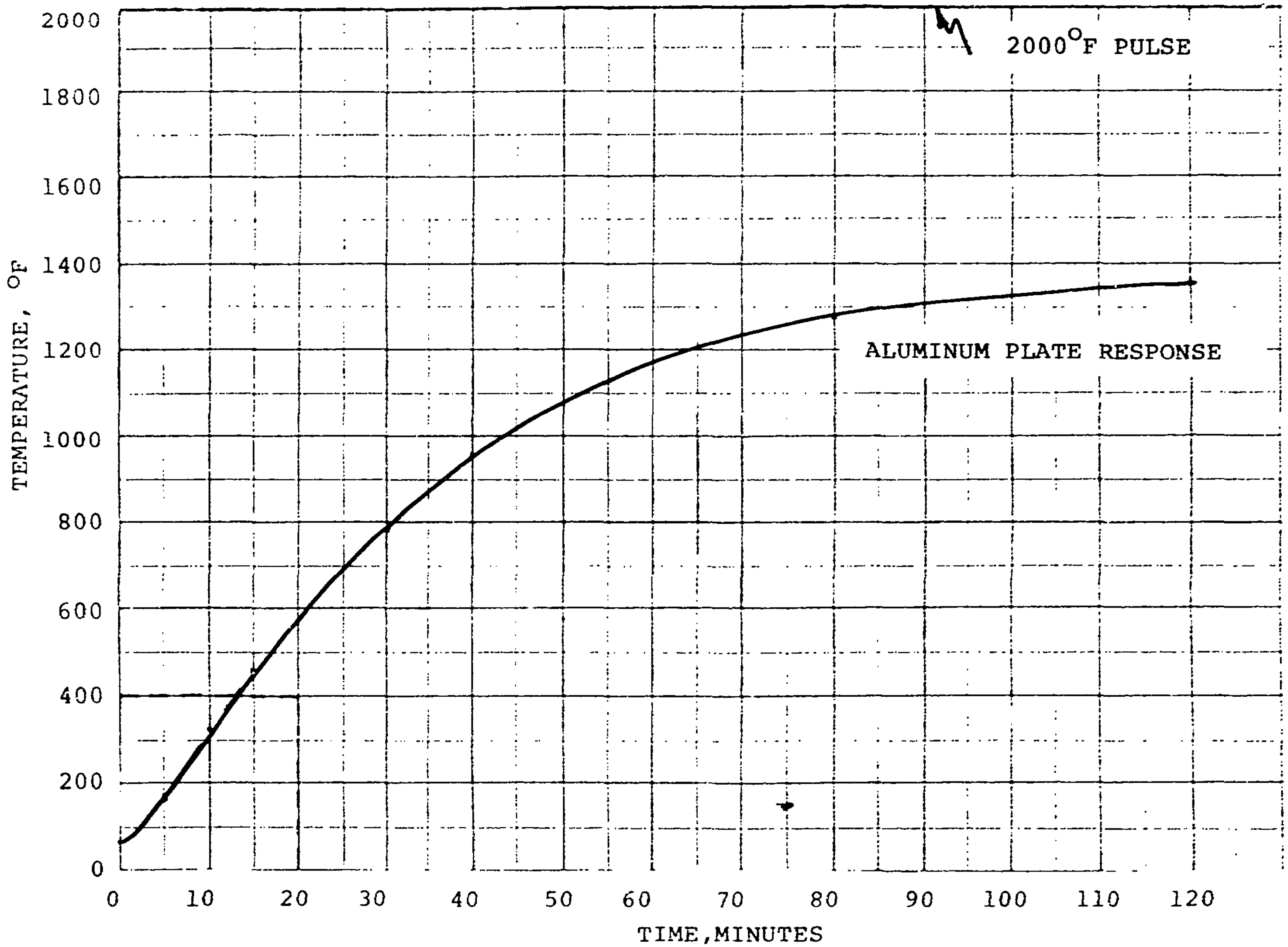
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS
DOUBLE INSULATED CONFIGURATION
HEATING 5 EVALUATION - **Q-FIBER -- 1 1/4 inch, 6pcf**

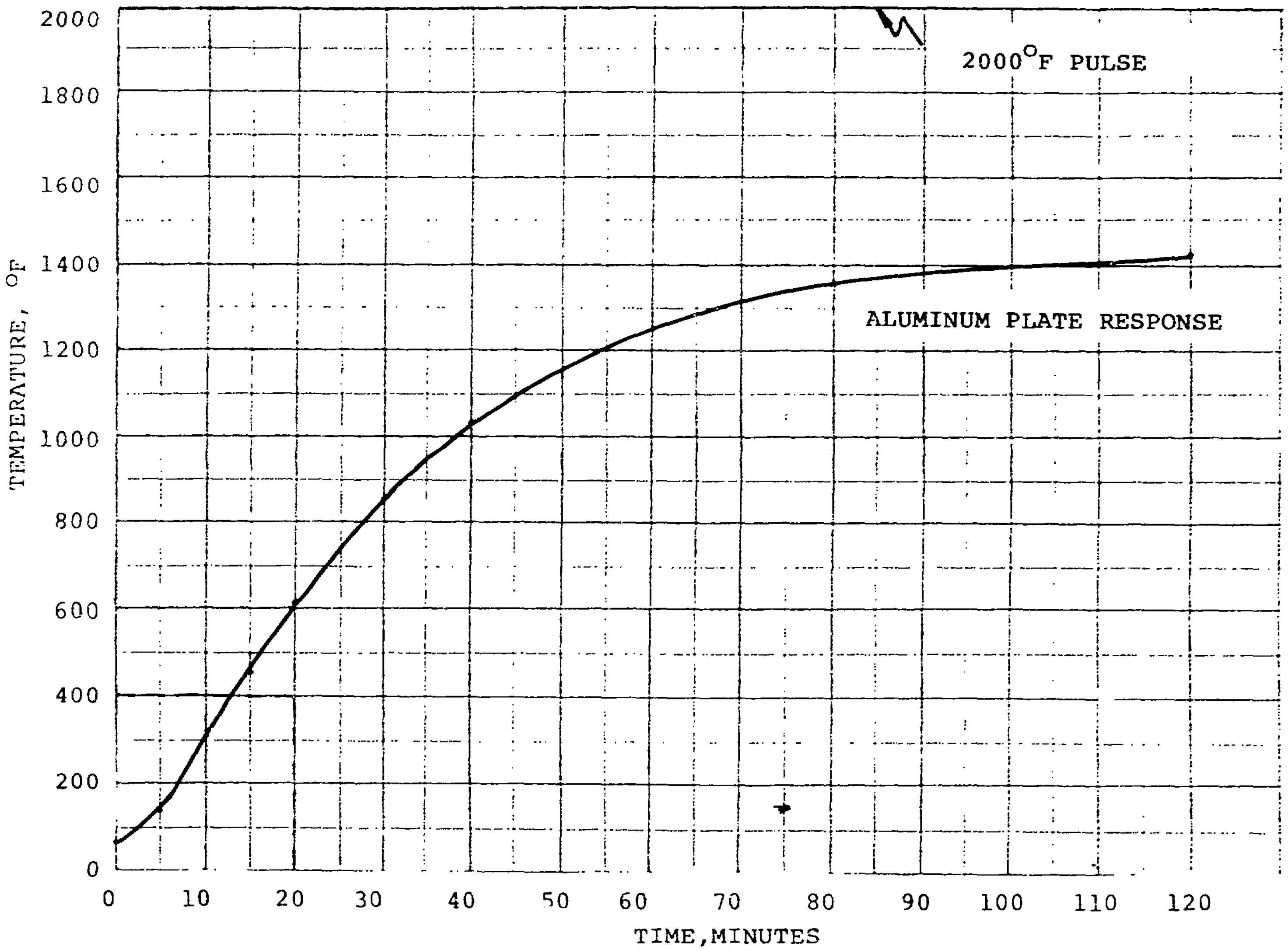
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS
DOUBLE INSULATED CONFIGURATION
HEATING 5 EVALUATION - **CERAFORM 126 -- 1 inch, 18.5pcf**

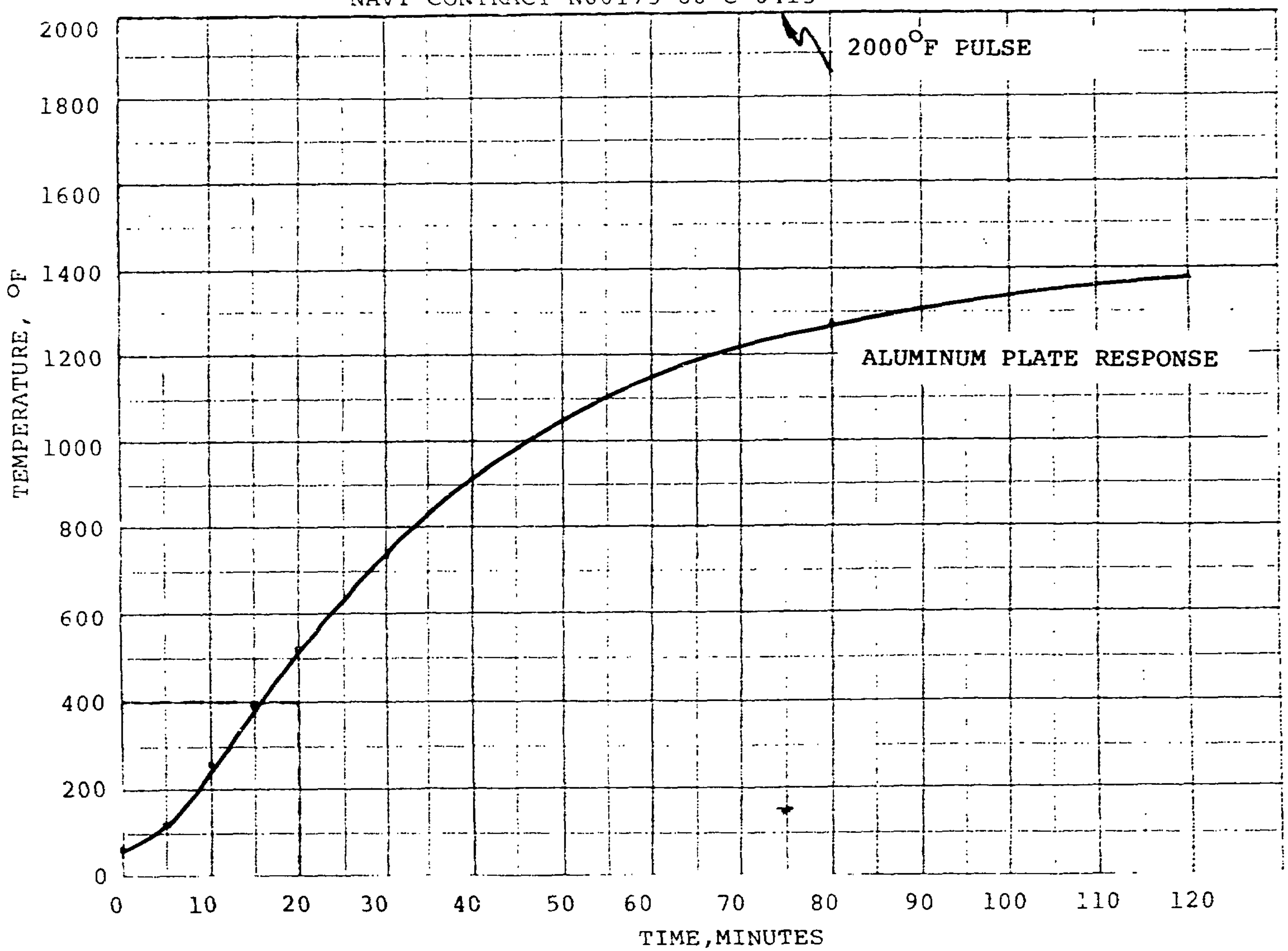
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS
DOUBLE INSULATED CONFIGURATION
HEATING 5 EVALUATION - **KAOWOOL -- 1 1/2 inch, 8pcf**

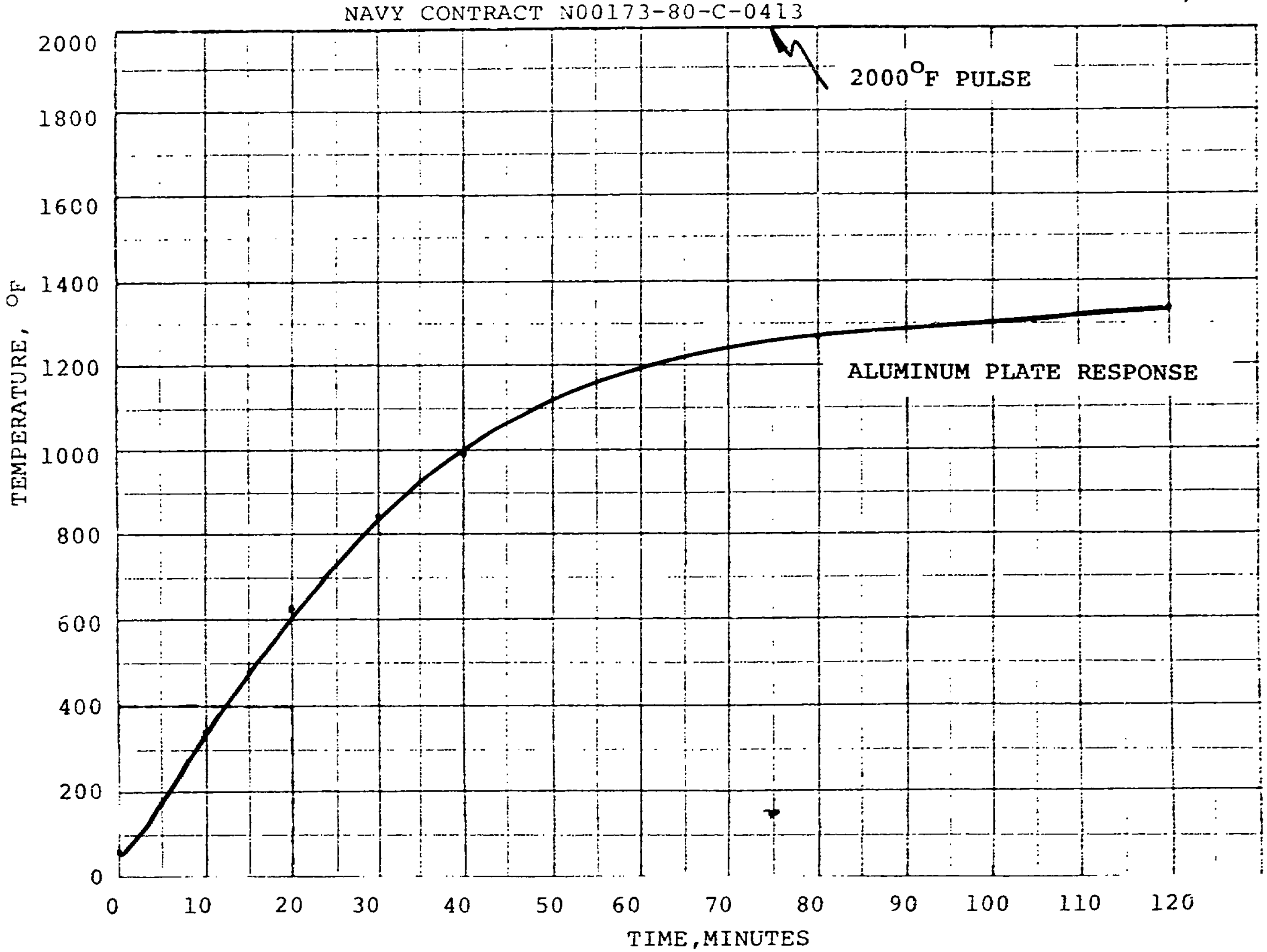
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS
DOUBLE INSULATED CONFIGURATION
HEATING 5 EVALUATION - **CERAFORM 126 -- 1/4 inch, 18.5pcf Plus Q-FIBER -- 1/2 inch, 6pcf**

NAVY CONTRACT N00173-80-C-0413



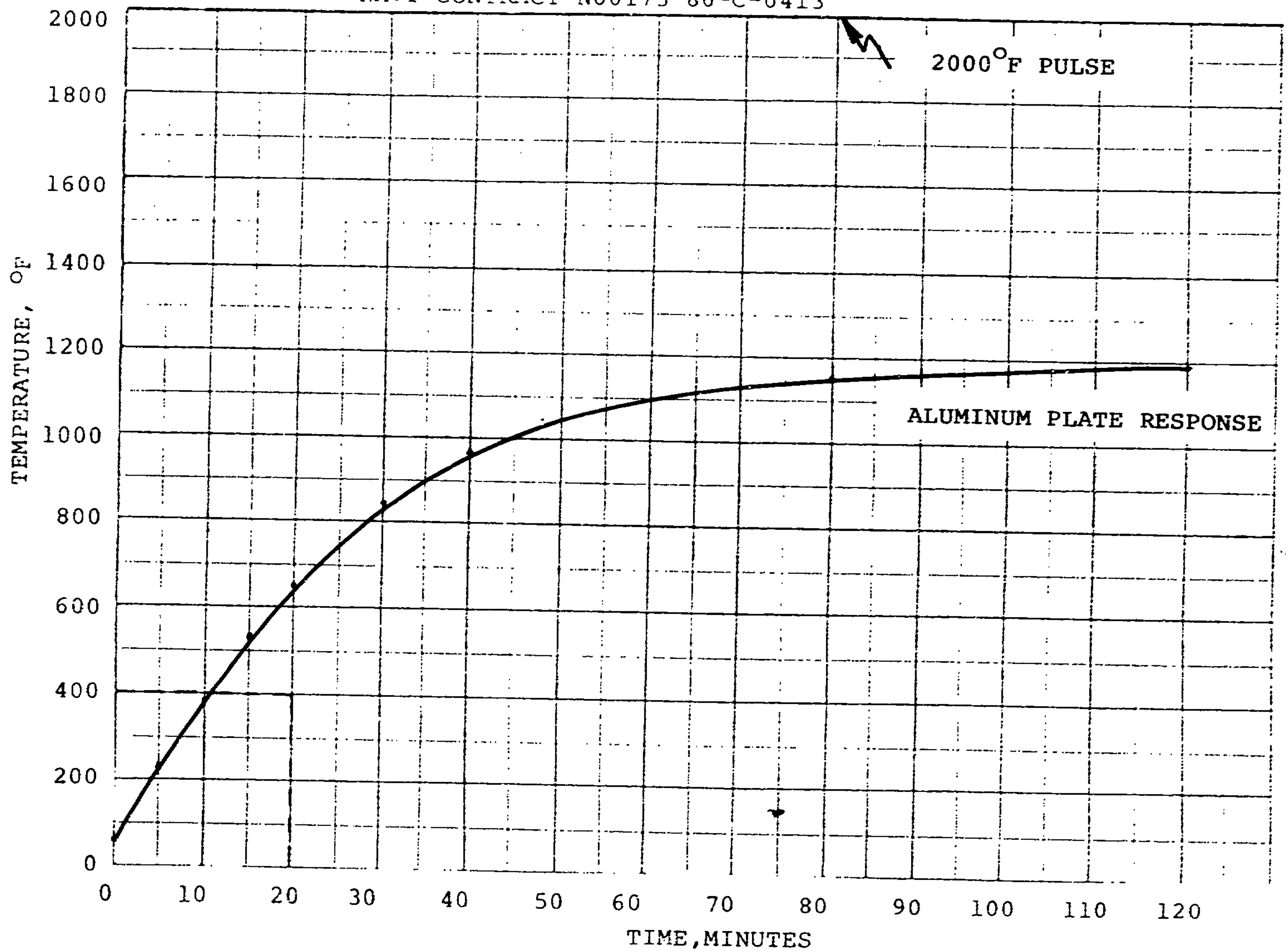
APPENDIX C

GRAPH OF RESULTS

DOUBLE INSULATED CONFIGURATION

HEATING 5 EVALUATION - **FLEXIBLE MIN-K -- 1/4 inch, 8pcf Core Plus CERAFELT- 1/4 inch, 4pcf**

NAVY CONTRACT N00173-80-C-0413



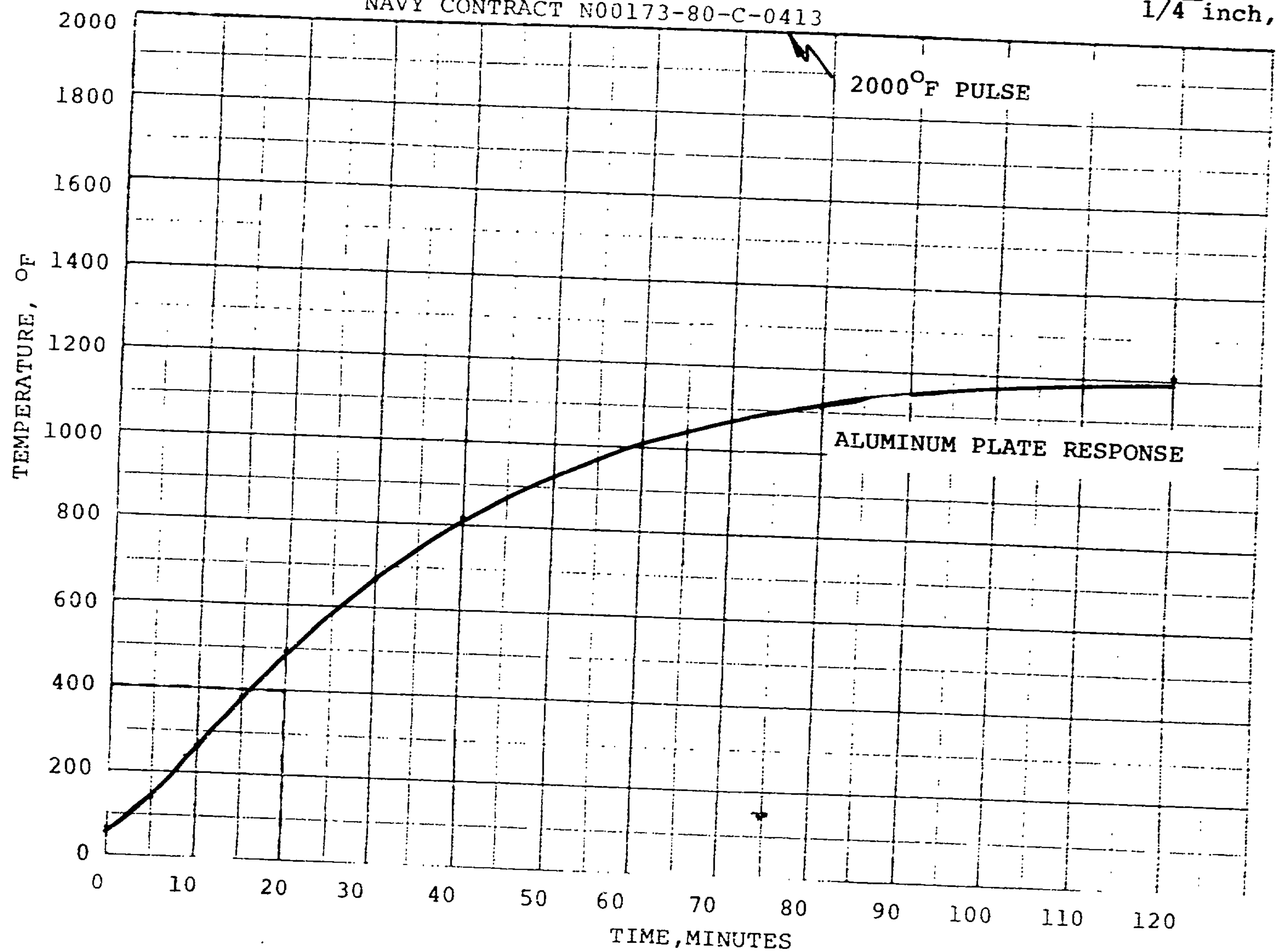
APPENDIX C

GRAPH OF RESULTS

DOUBLE INSULATED CONFIGURATION

HEATING 5 EVALUATION - **MIN-K TE1400 -- 1/4 inch, 20pcf Plus MICROLITE B -- 1/4 inch, 4.5pcf**

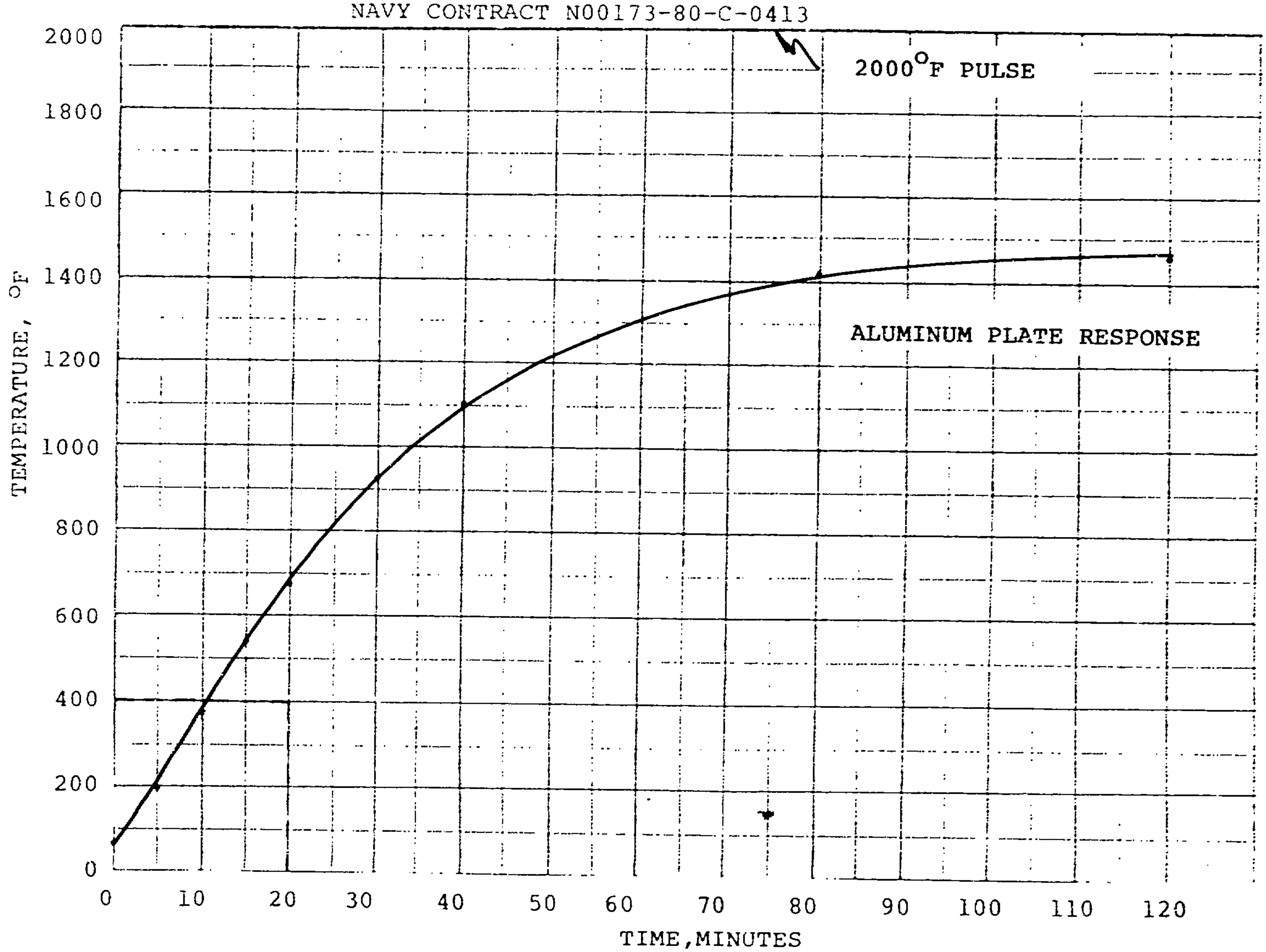
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS
DOUBLE INSULATED CONFIGURATION
HEATING 5 EVALUATION - **CERAFELT -- 1 inch, 6pcf**

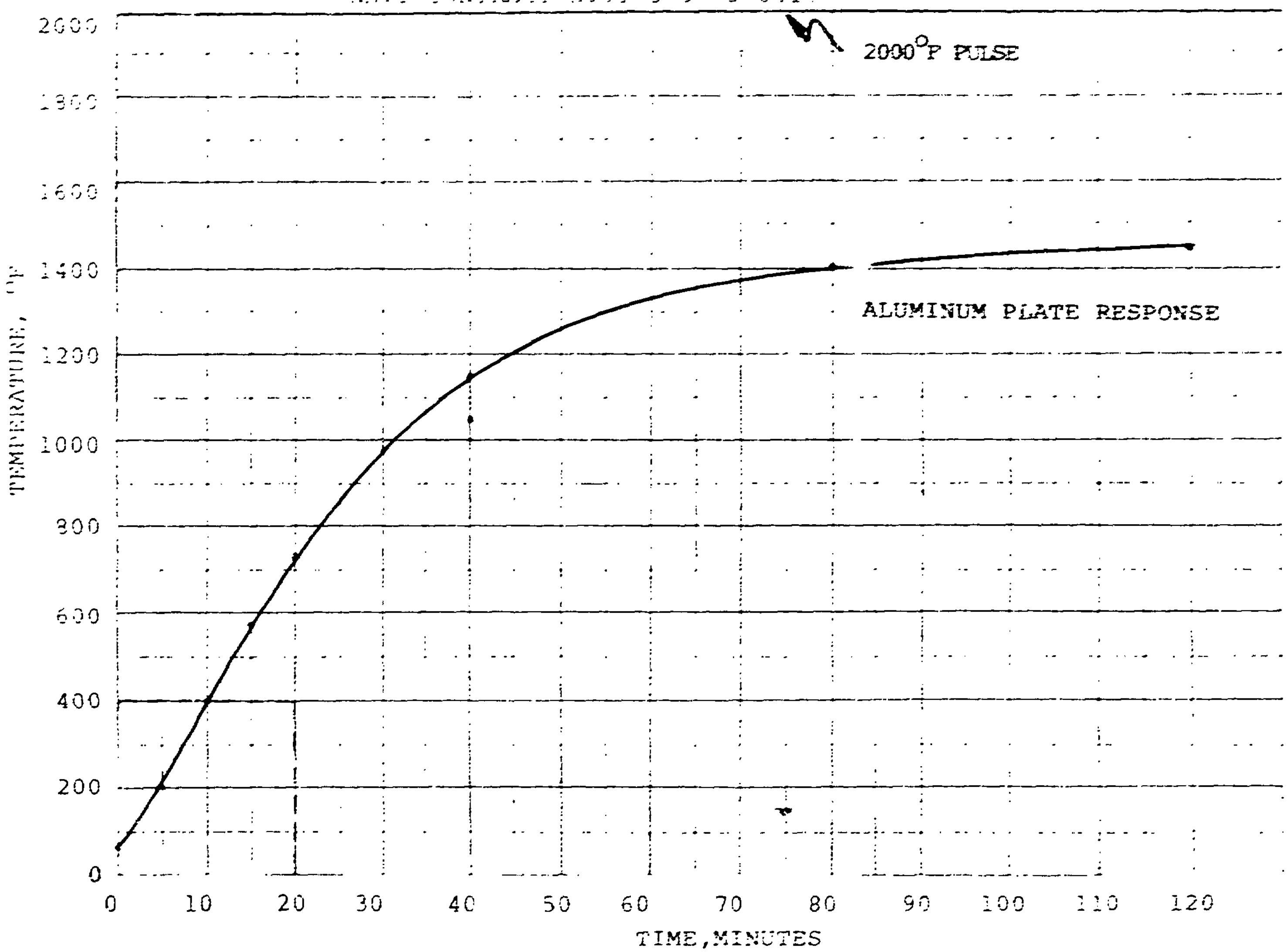
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

DOUBLE INSULATED CONFIGURATION

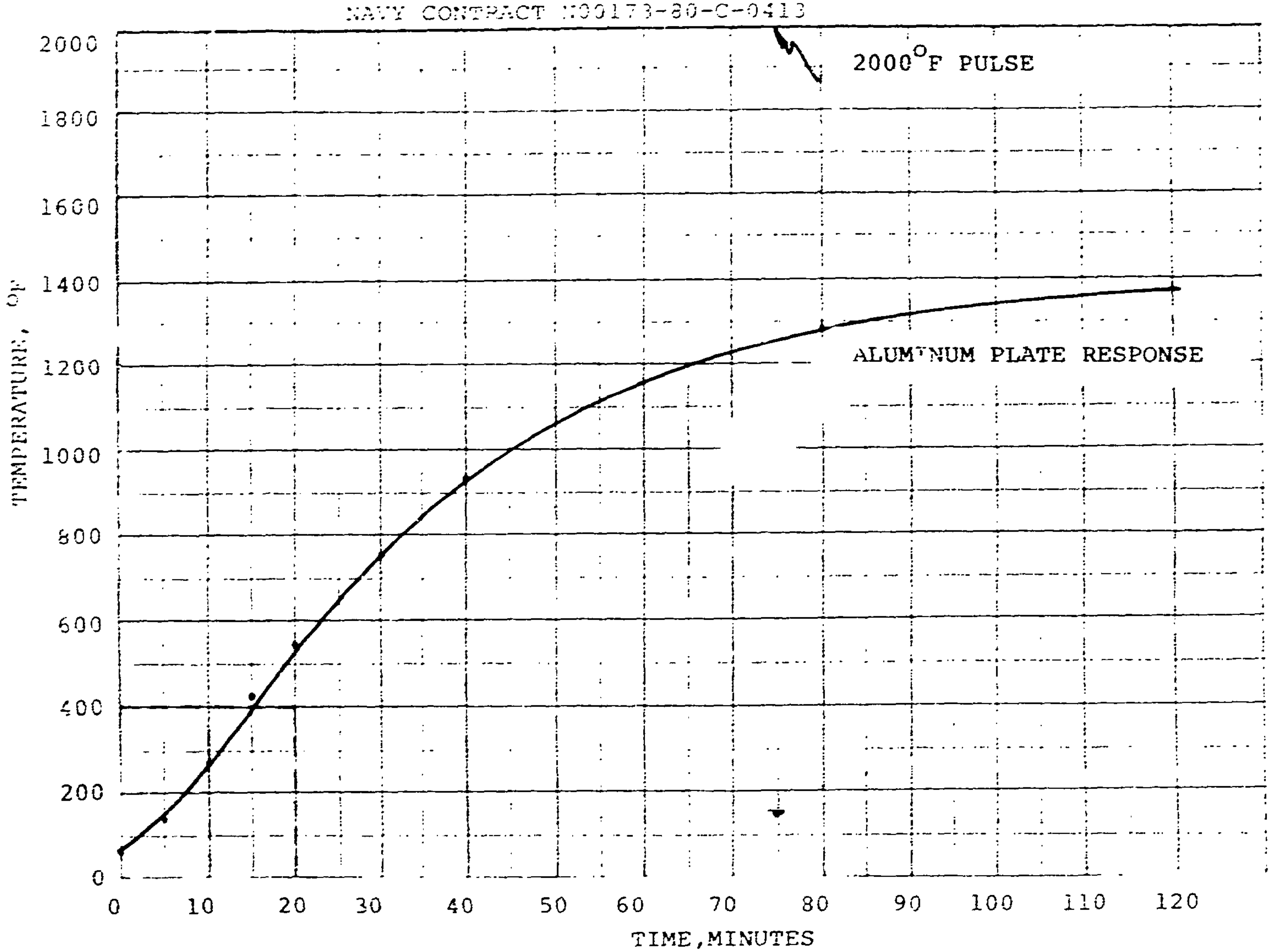
THERMOFLEX II -- 3/4 inch, 12pcf



APPENDIX C

GRAPH OF RESULTS
DOUBLE INSULATED CONFIGURATION
HEATING 5 EVALUATION - CERAFIBER -- 2 inch, 6pcf

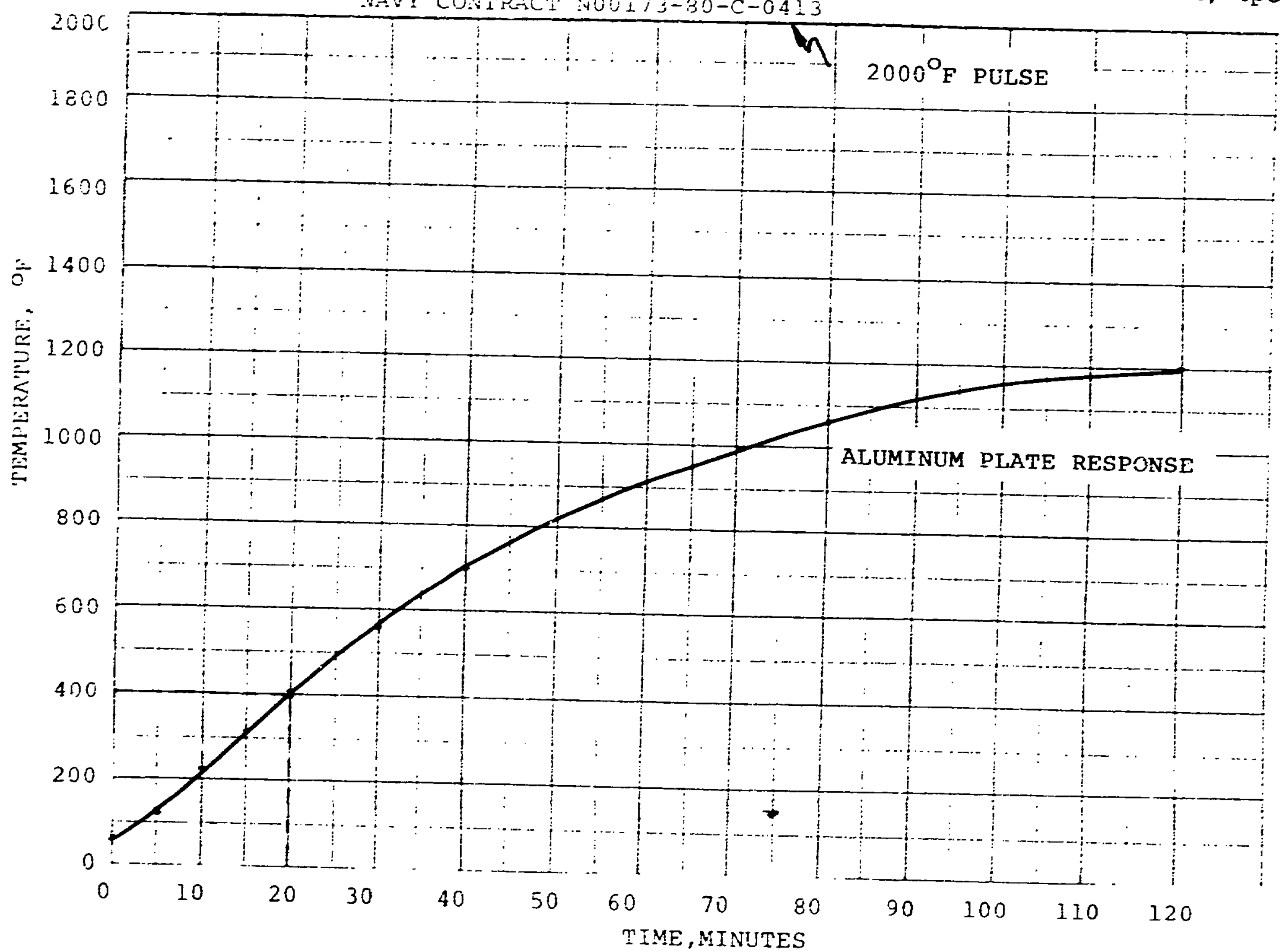
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS
DOUBLE INSULATED CONFIGURATION
HEATING 5 EVALUATION - FLEXIBLE MIN-K -- 1/4 inch, 8pcf Core Plus CERAFELT -- 1 inch, 4pcf

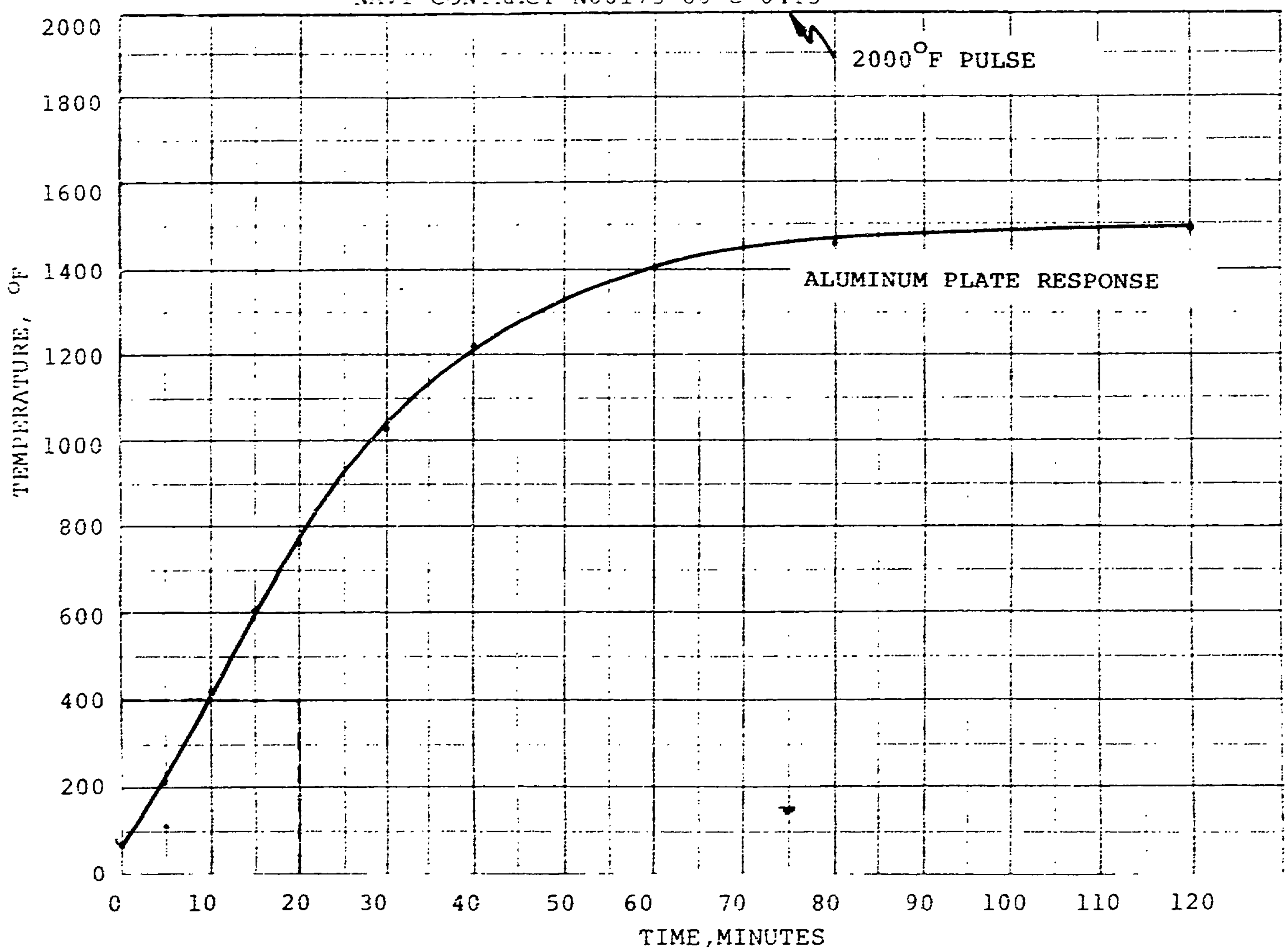
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS
DOUBLE INSULATED CONFIGURATION
HEATING 5 EVALUATION - CERAFORM 126 -- 1/4 inch, 18.5pcf Plus
LO-CON -- 1/2 inch, 6pcf

NAVY CONTRACT N00173-80-C-0413



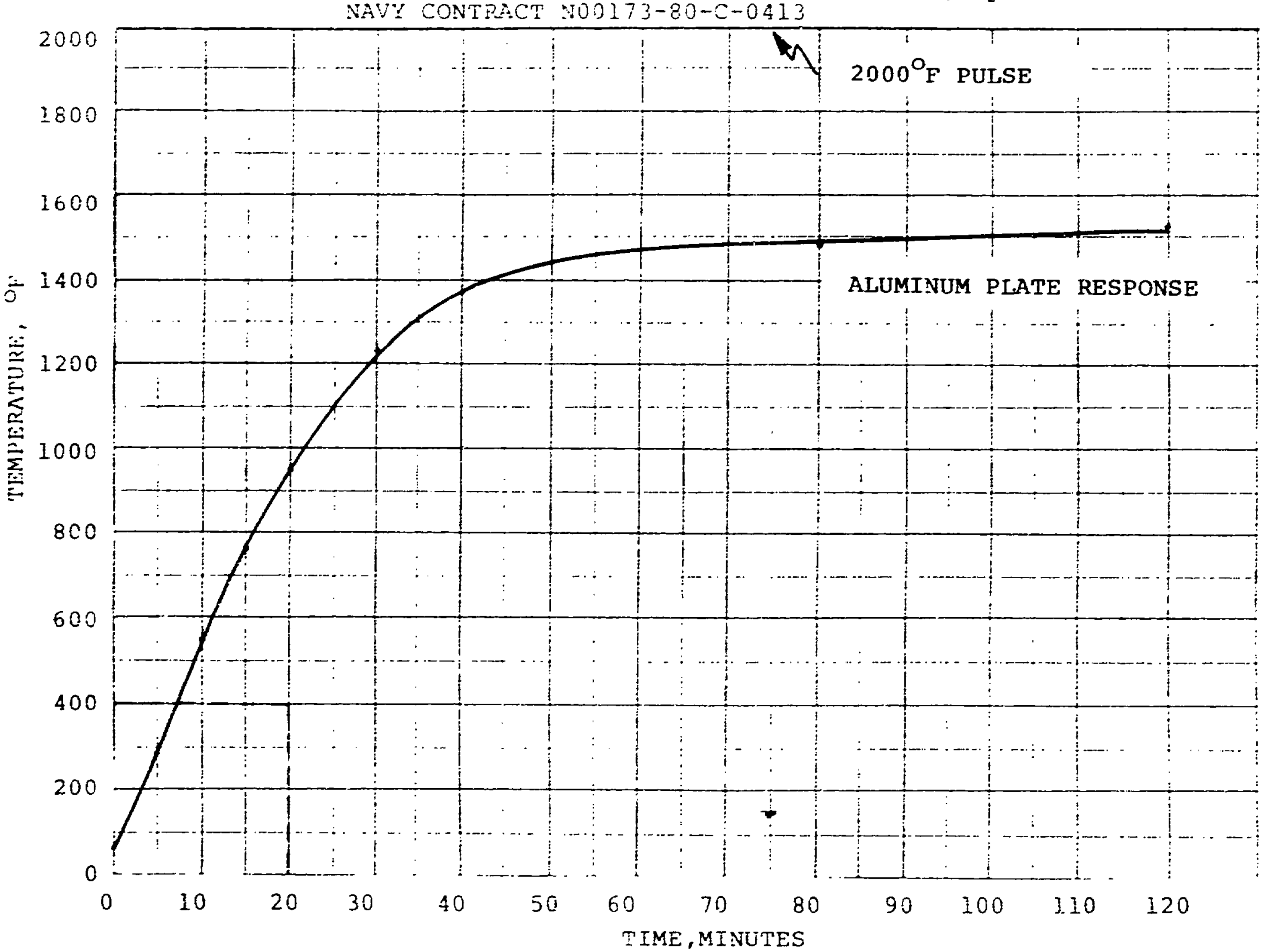
APPENDIX C

GRAPH OF RESULTS

DOUBLE INSULATED CONFIGURATION

HEATING 5 EVALUATION - **CERAFORM 103 -- 1/4 inch, 13.5pcf Plus**
CERAFELT -- 1/2 inch, 4pcf

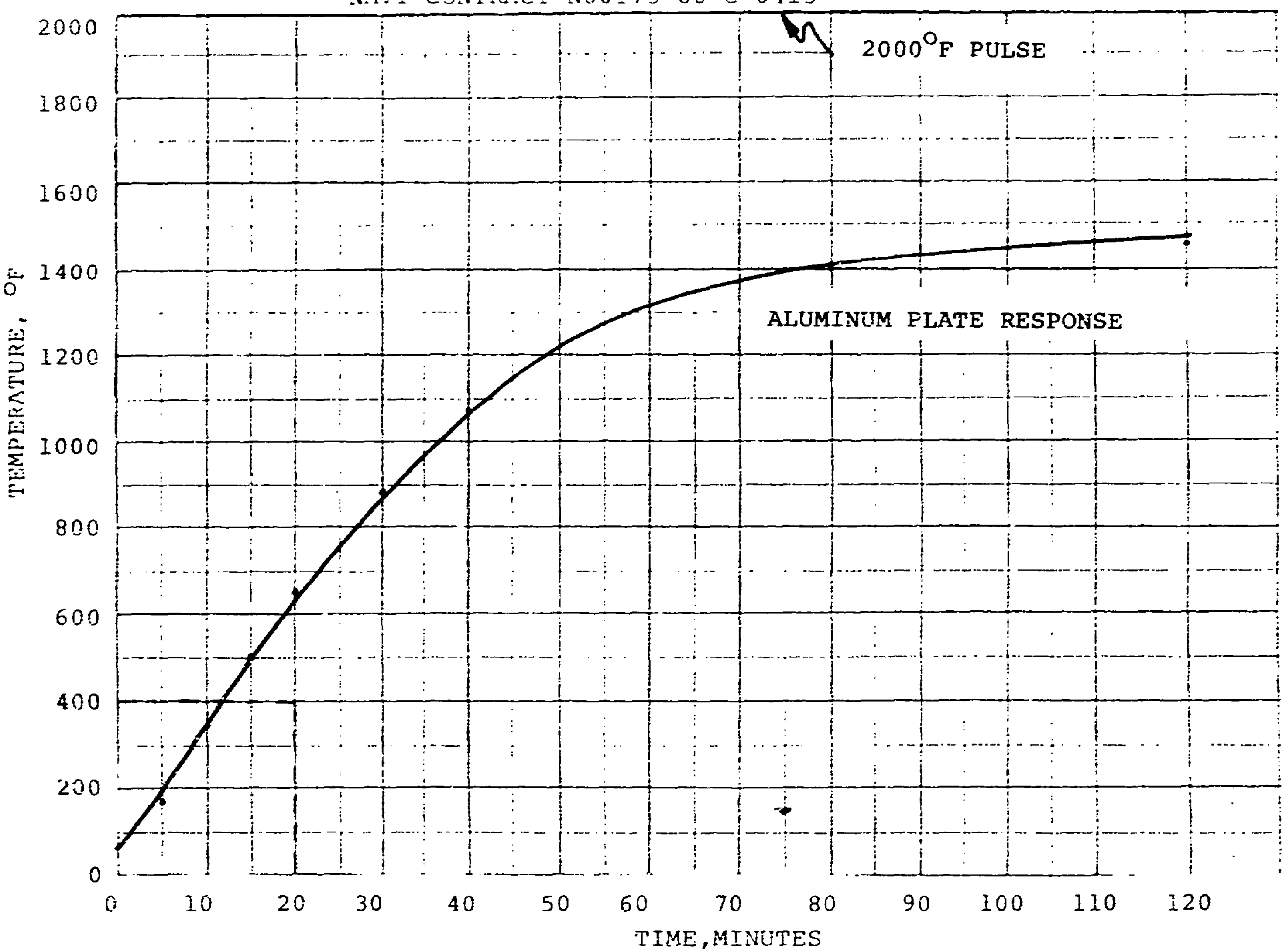
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS
DOUBLE INSULATED CONFIGURATION
HEATING 5 EVALUATION - LO-CON -- 1 inch, 6pcf

NAVY CONTRACT N00173-80-C-0413

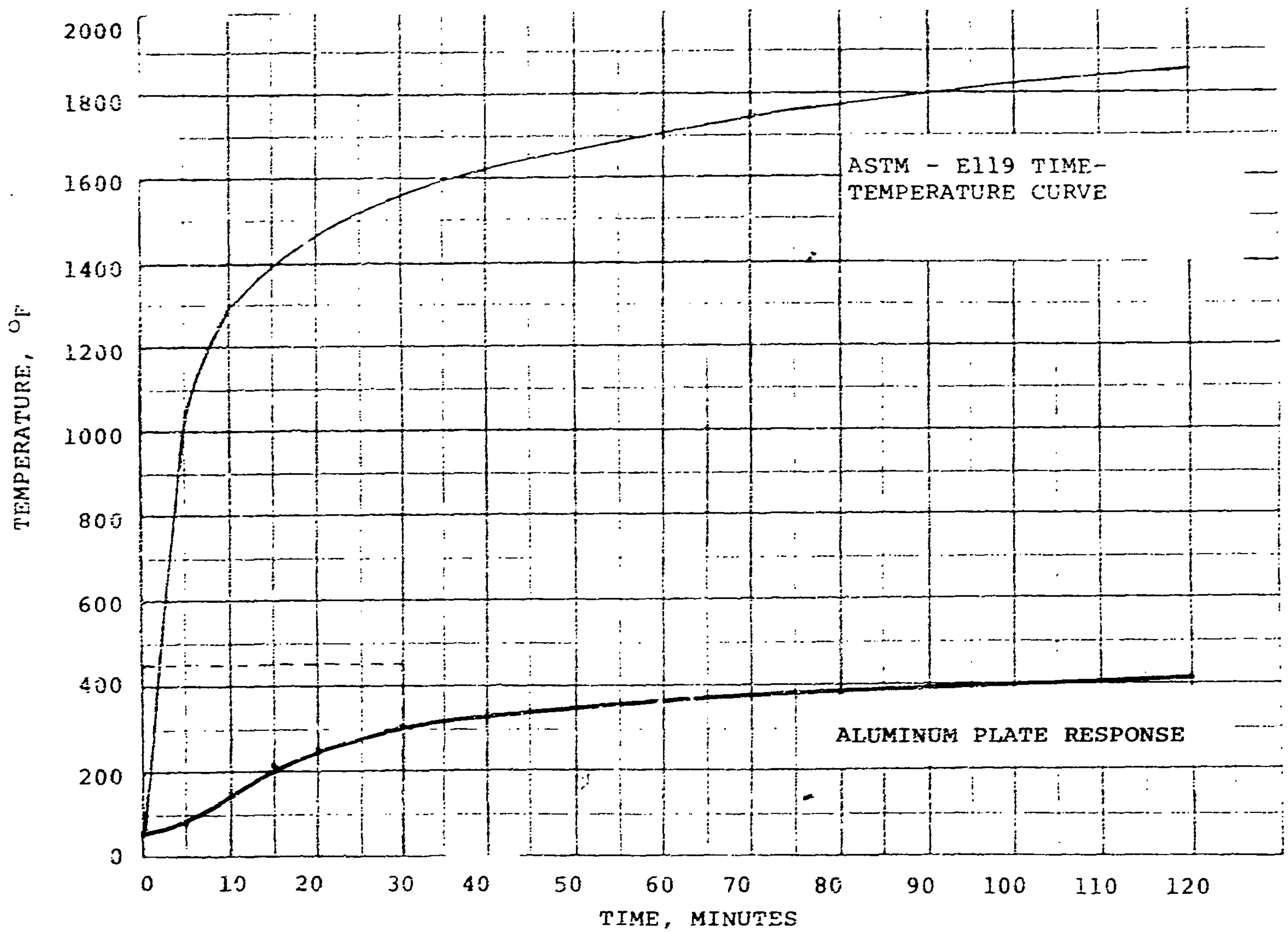


APPENDIX C

GRAPH OF RESULTS

HEATING 5 EVALUATION - CERAFELT -- 1 inch, 4 pcf
SINGLE INSULATED CONFIGURATION

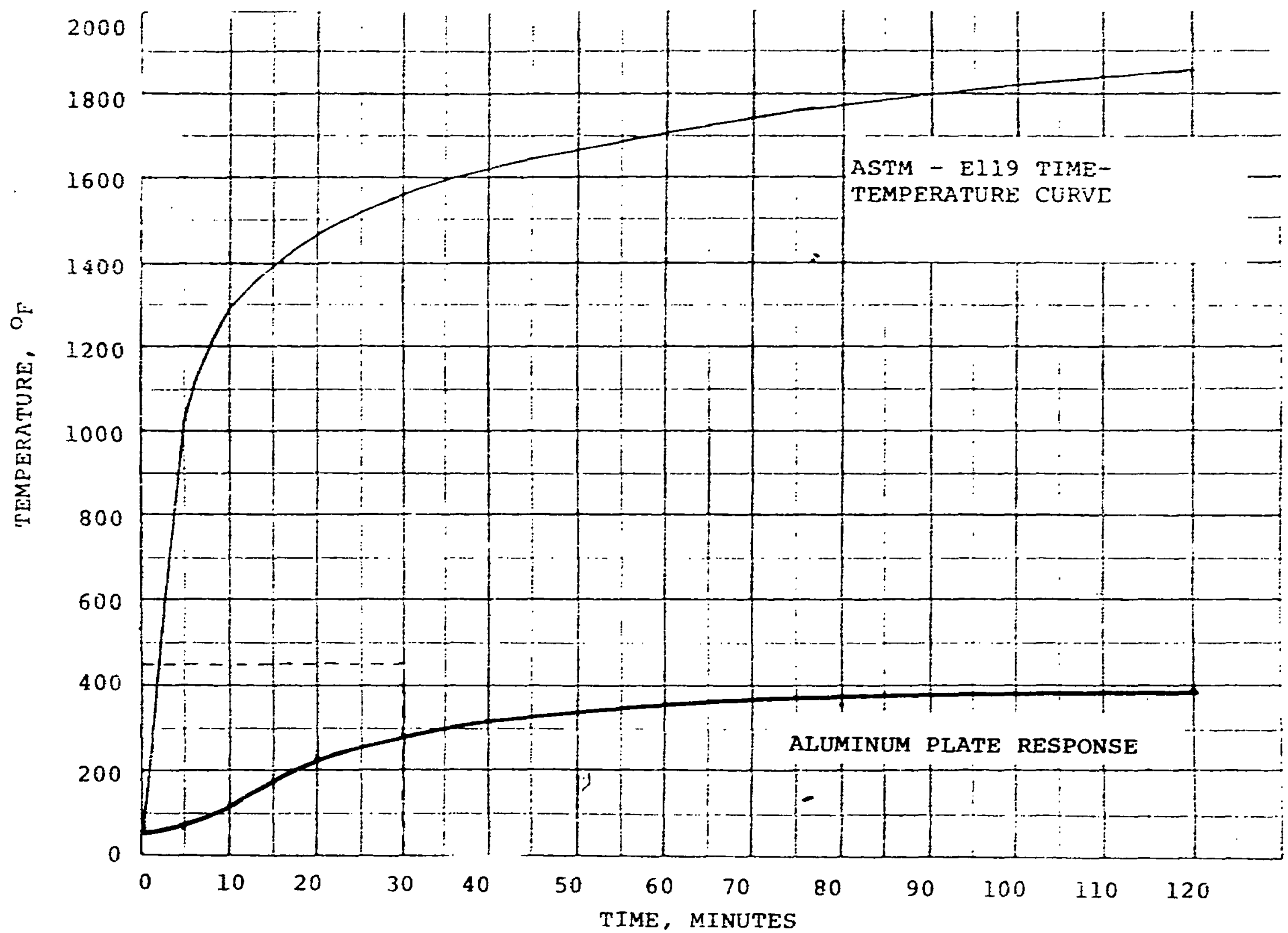
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

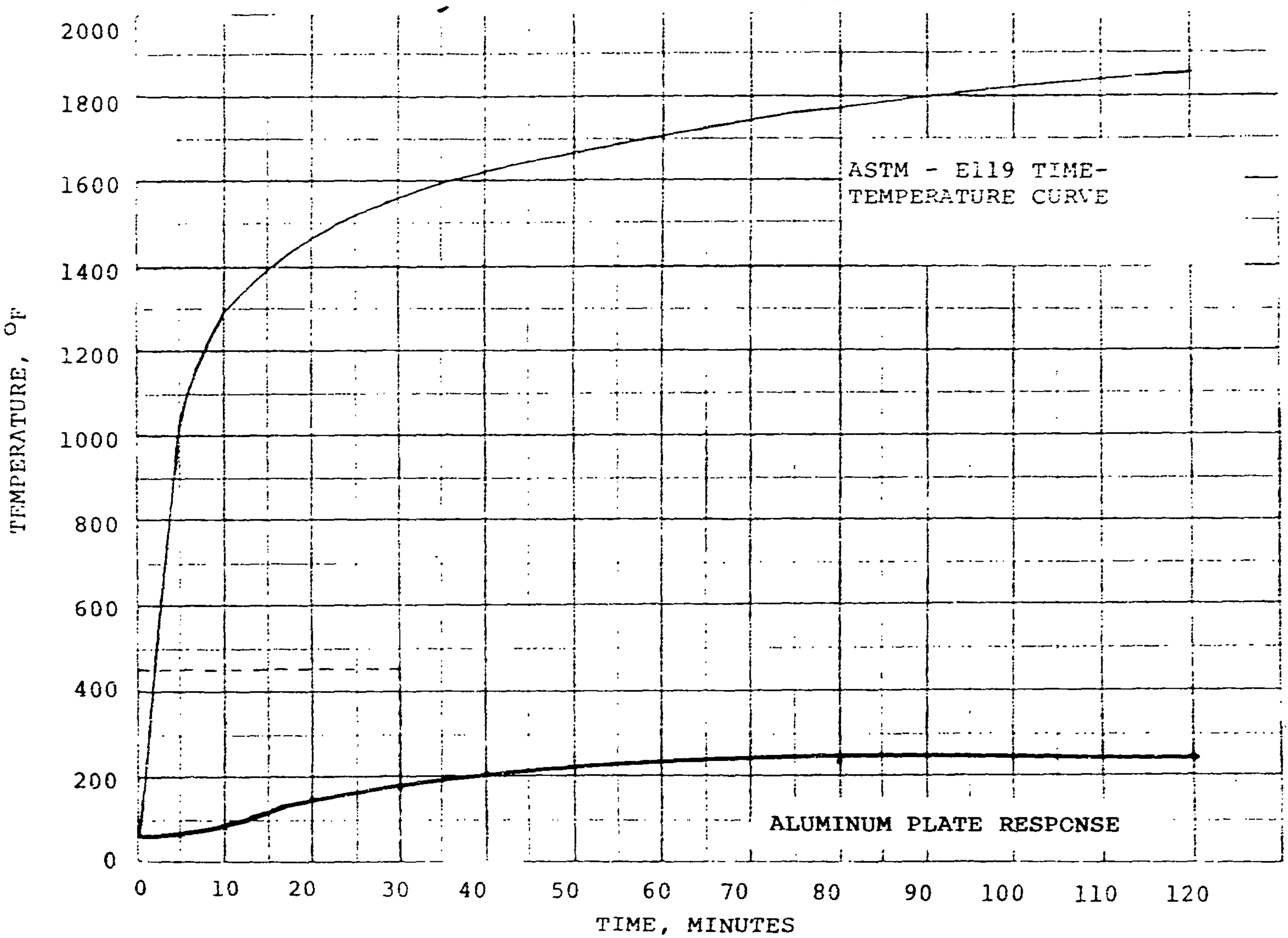
HEATING 5 EVALUATION - CERAFIBER -- 1 1/2 inch, 6 pcf
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

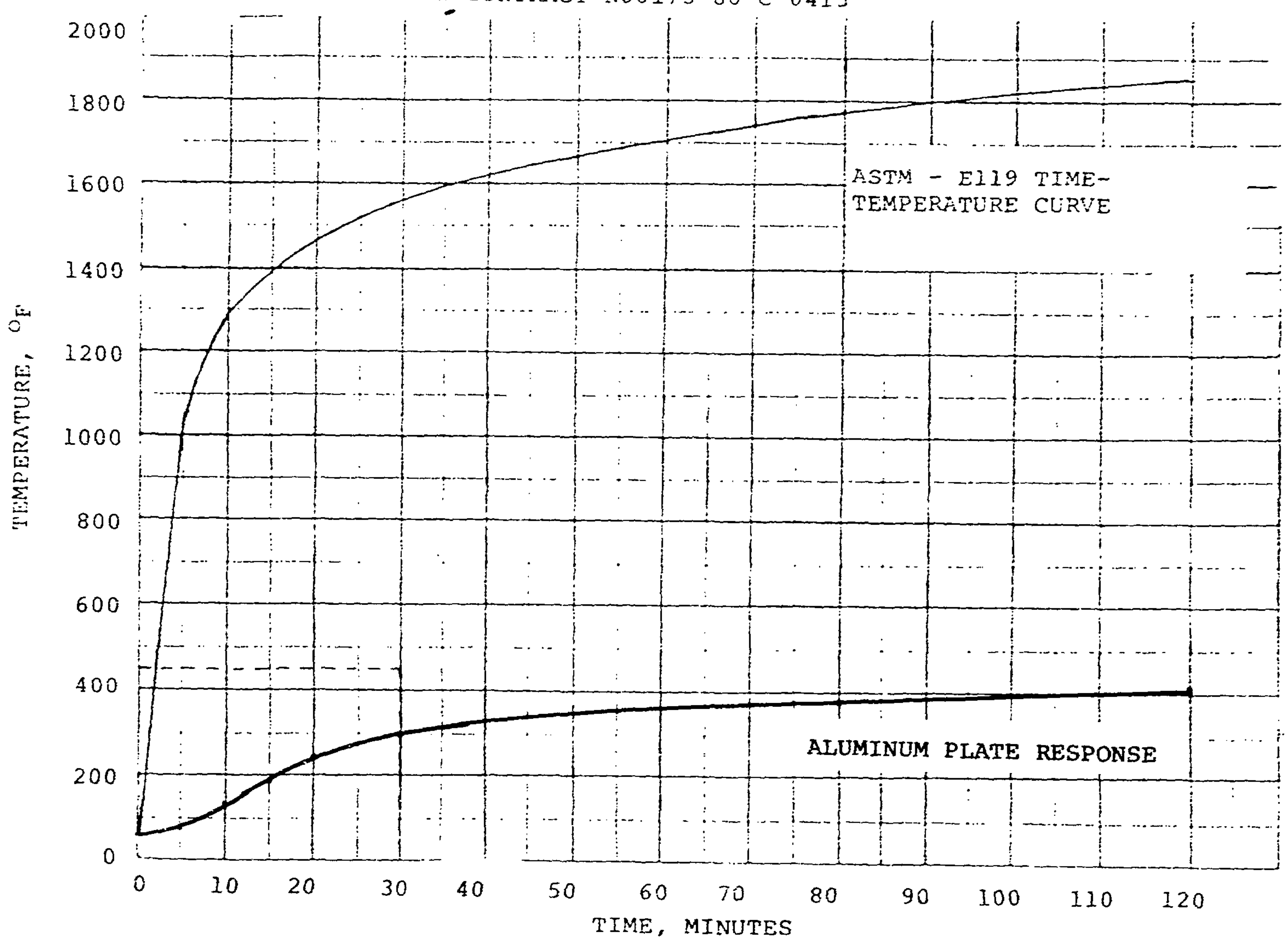
HEATING 5 EVALUATION - MIN - K TE1400 -- 1/2 inch, 20pcf
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

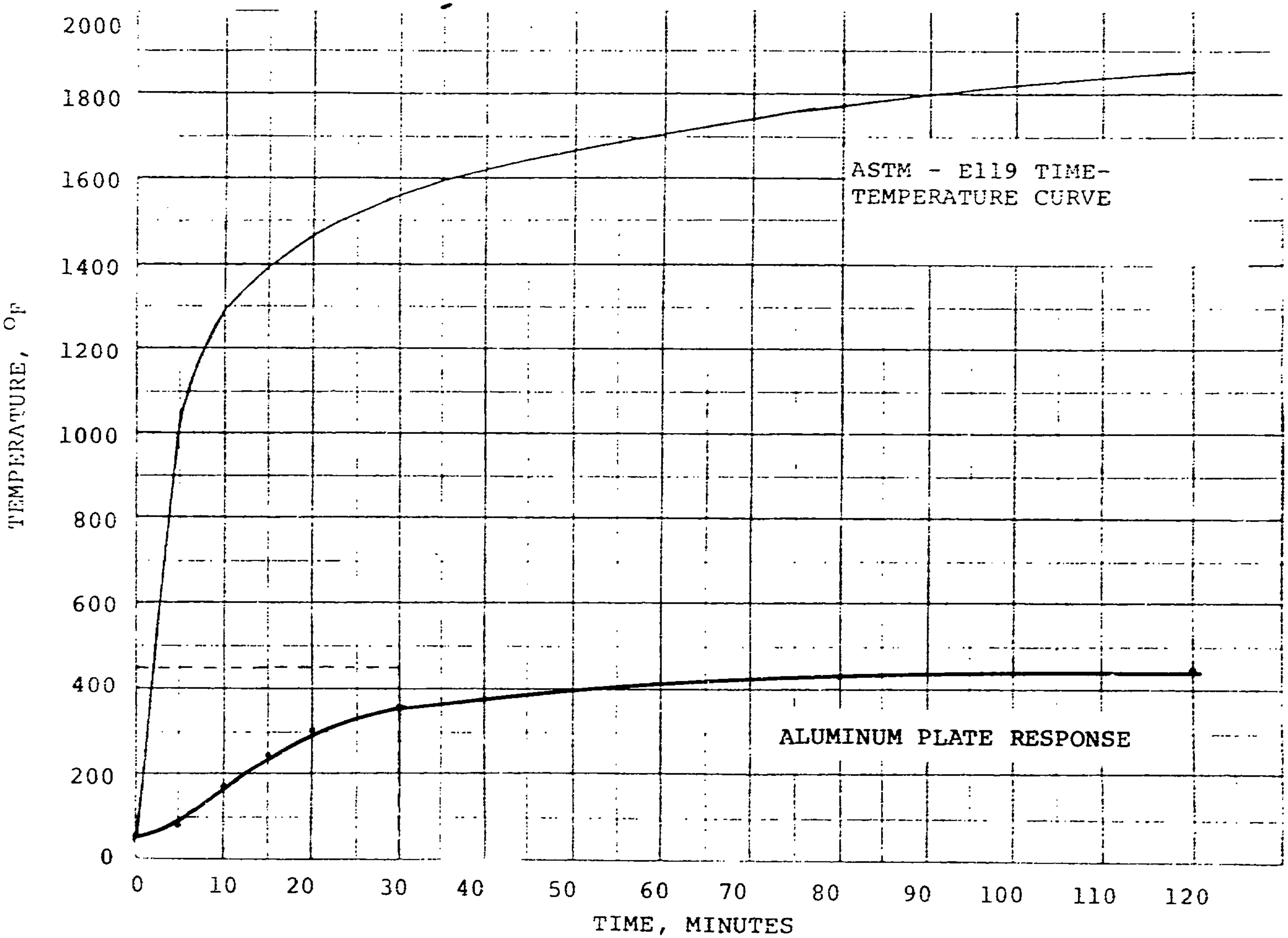
HEATING 5 EVALUATION - **CERAFELT -- 1 inch, 8pcf**
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

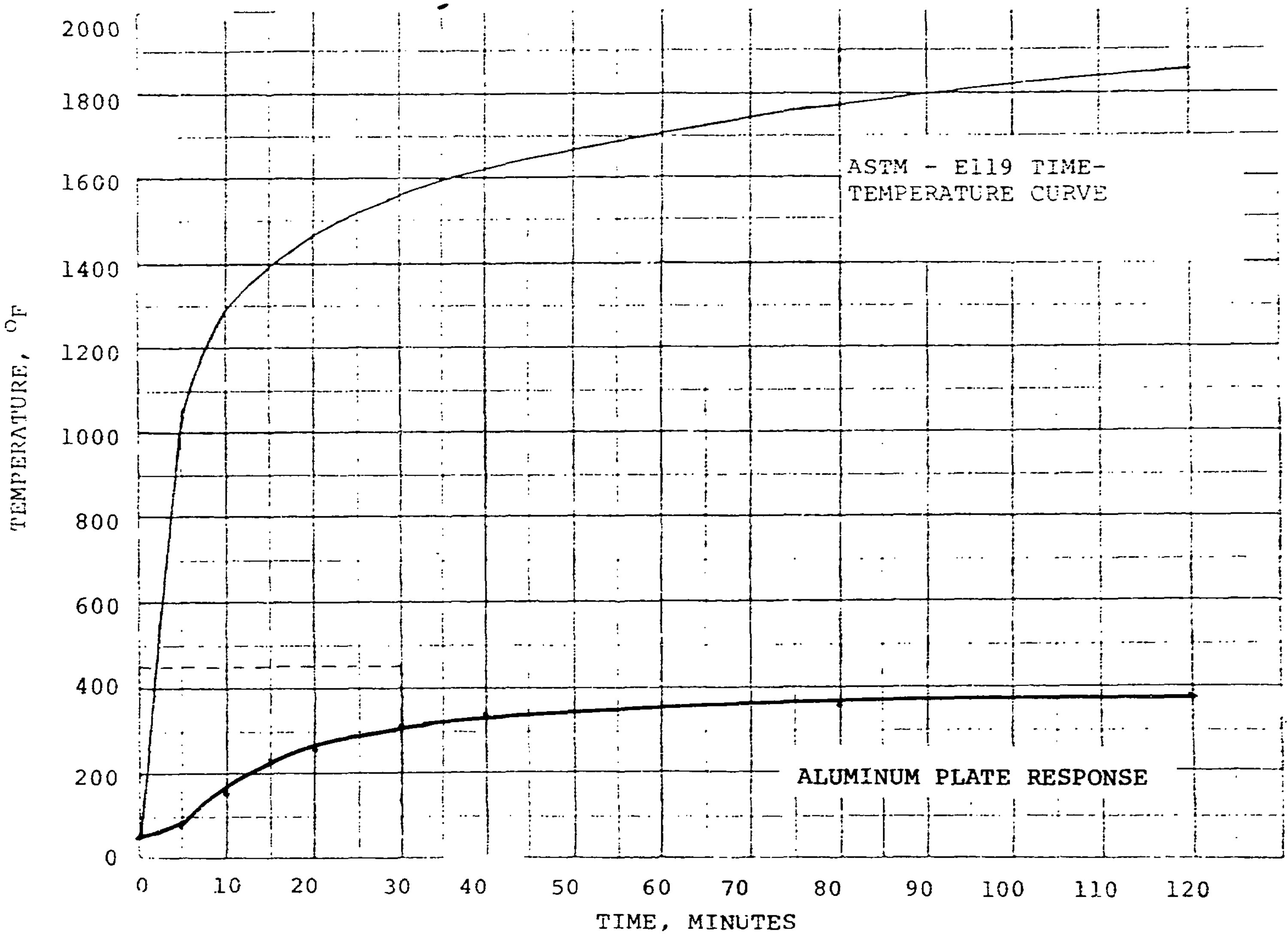
HEATING 5 EVALUATION - FLEXIBLE MIN-K -- 3/8 inch, 10 pcf core
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

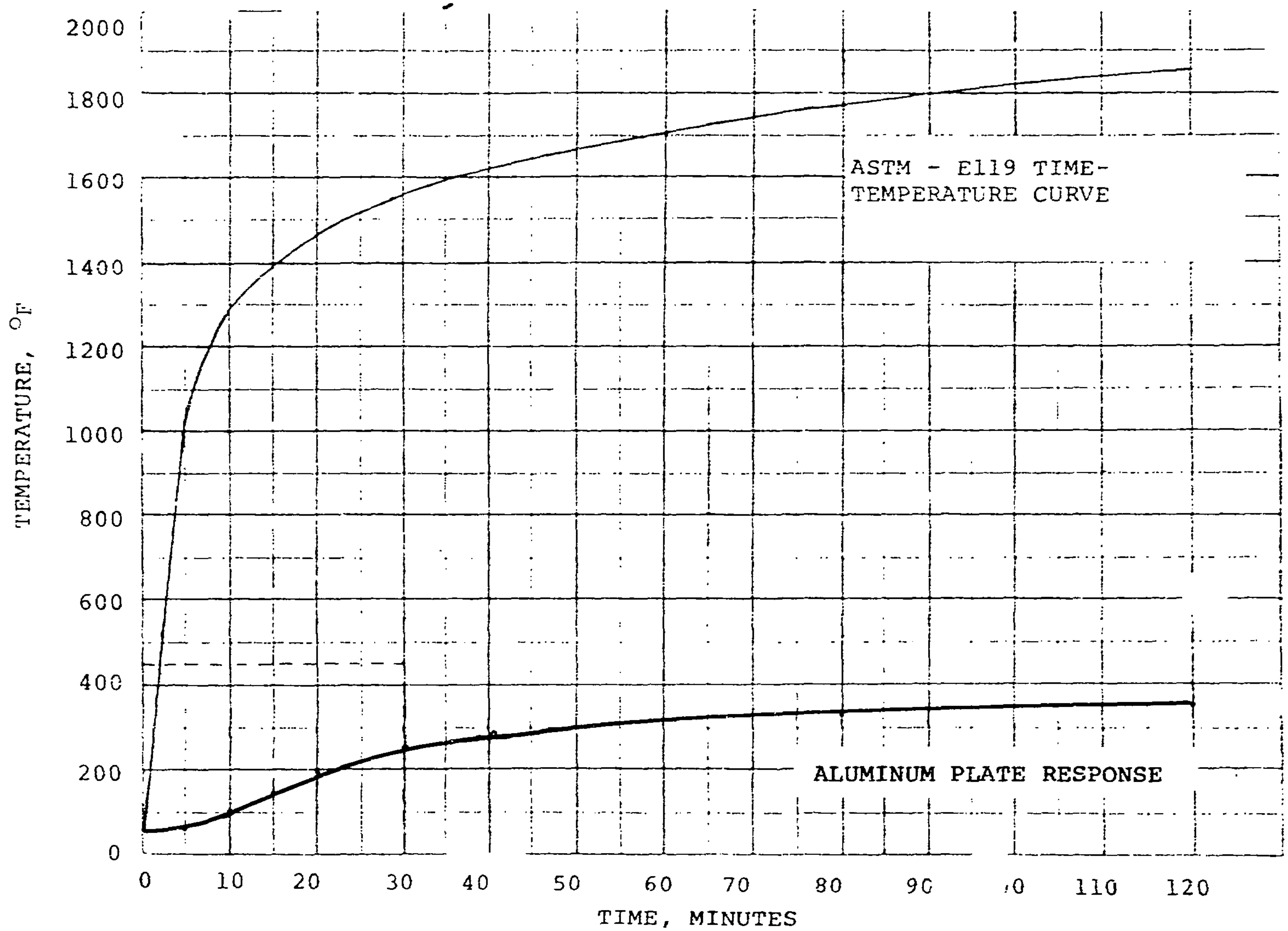
HEATING 5 EVALUATION - FLEXIBLE MIN-K -- 1/2 inch, 8pcf core
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

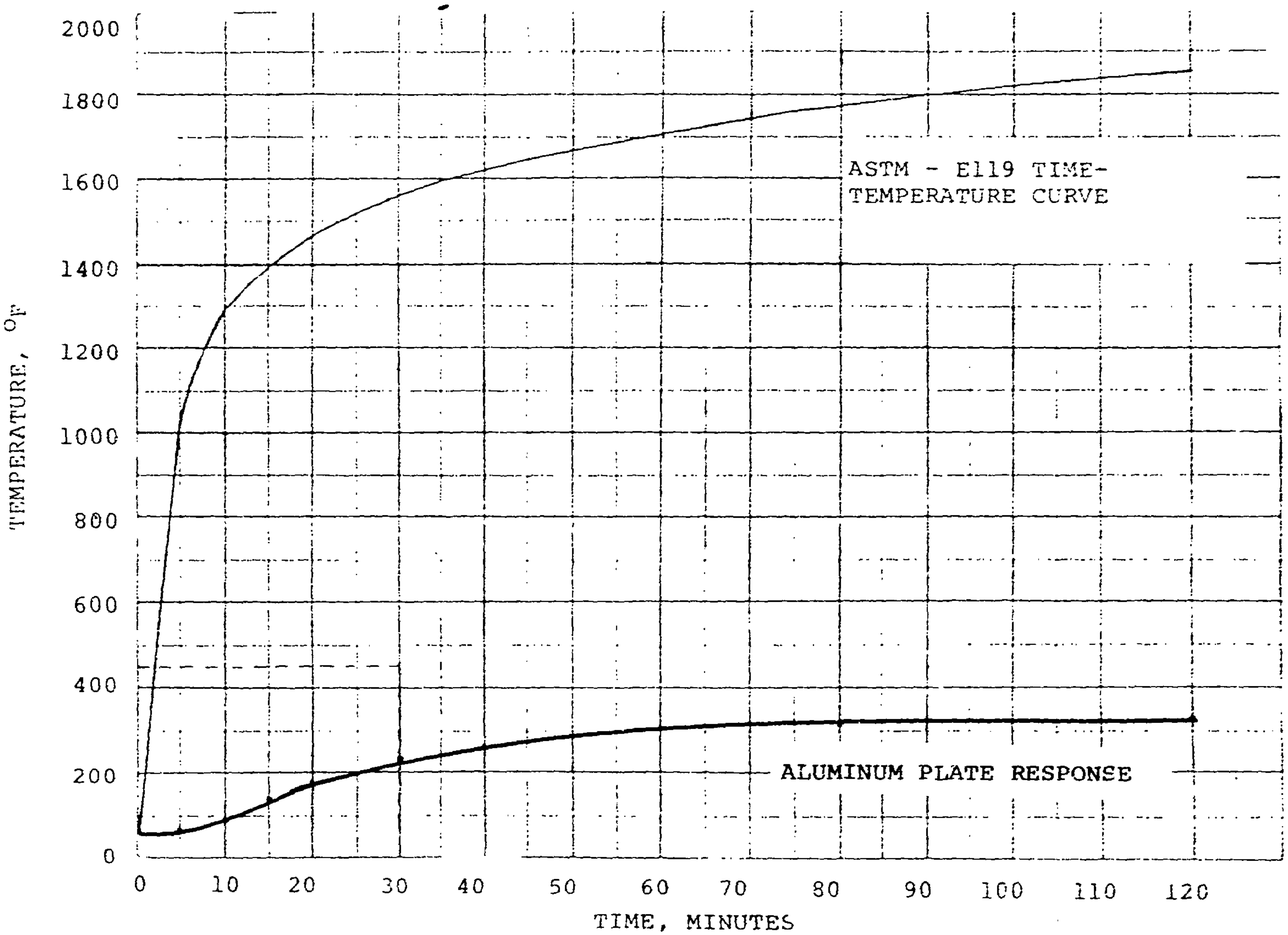
HEATING 5 EVALUATION - **CERAFELT -- 2 inch, 4pcf**
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

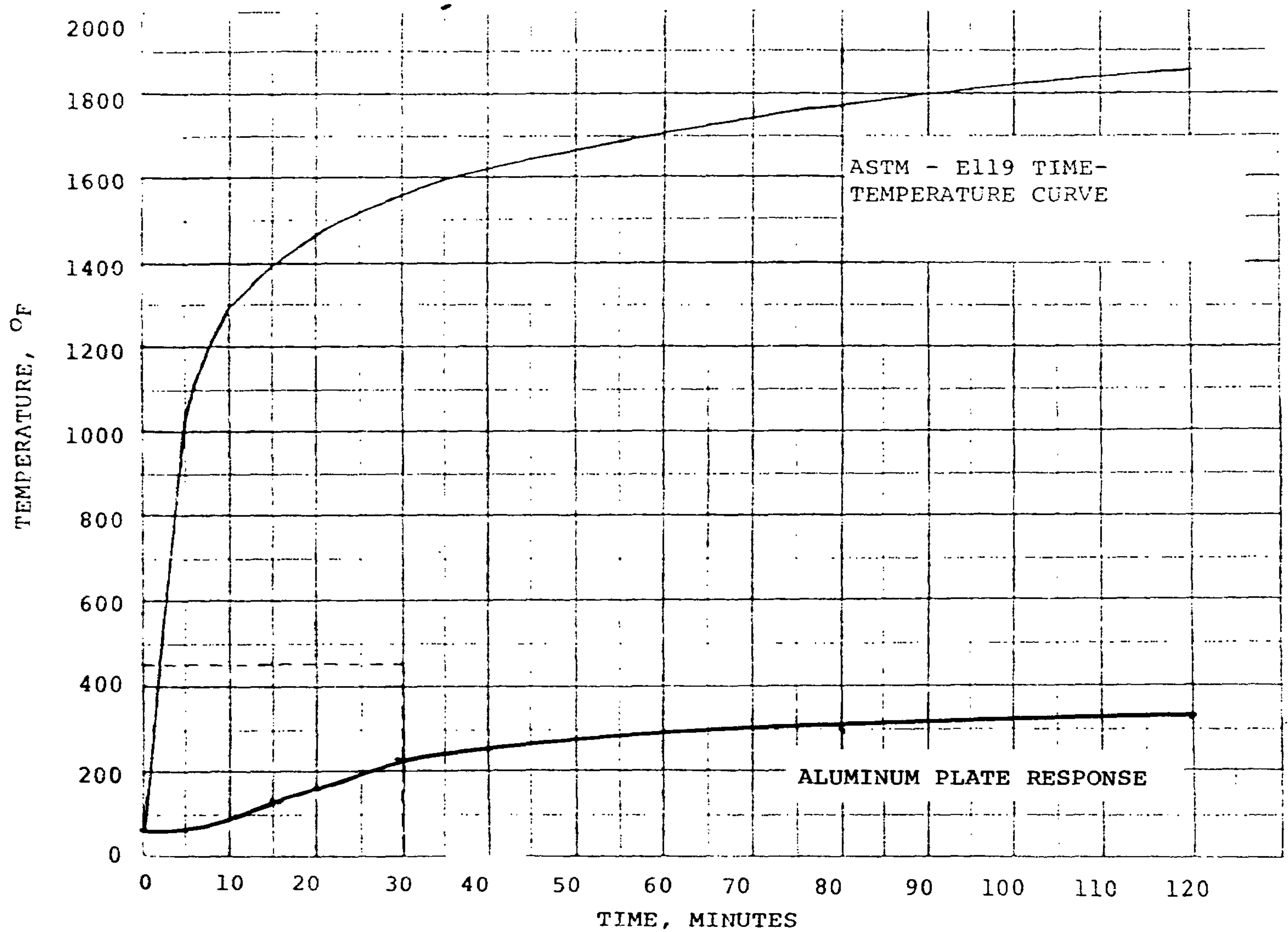
HEATING 5 EVALUATION - CERAFIBER -- 2 inch, 6 pcf
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

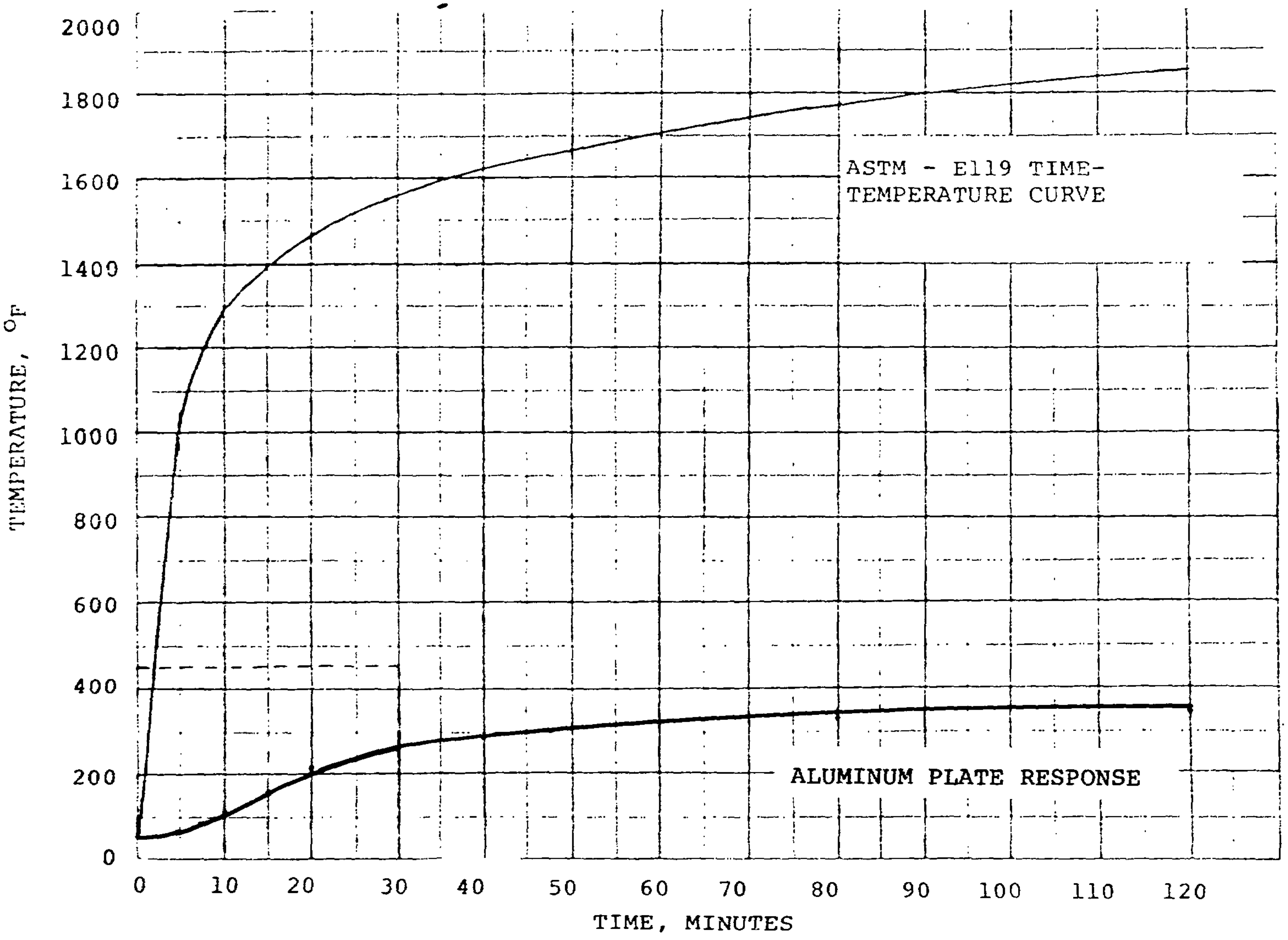
HEATING 5 EVALUATION - **KAOWOOL** -- 1 1/2 inch, 8pcf
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

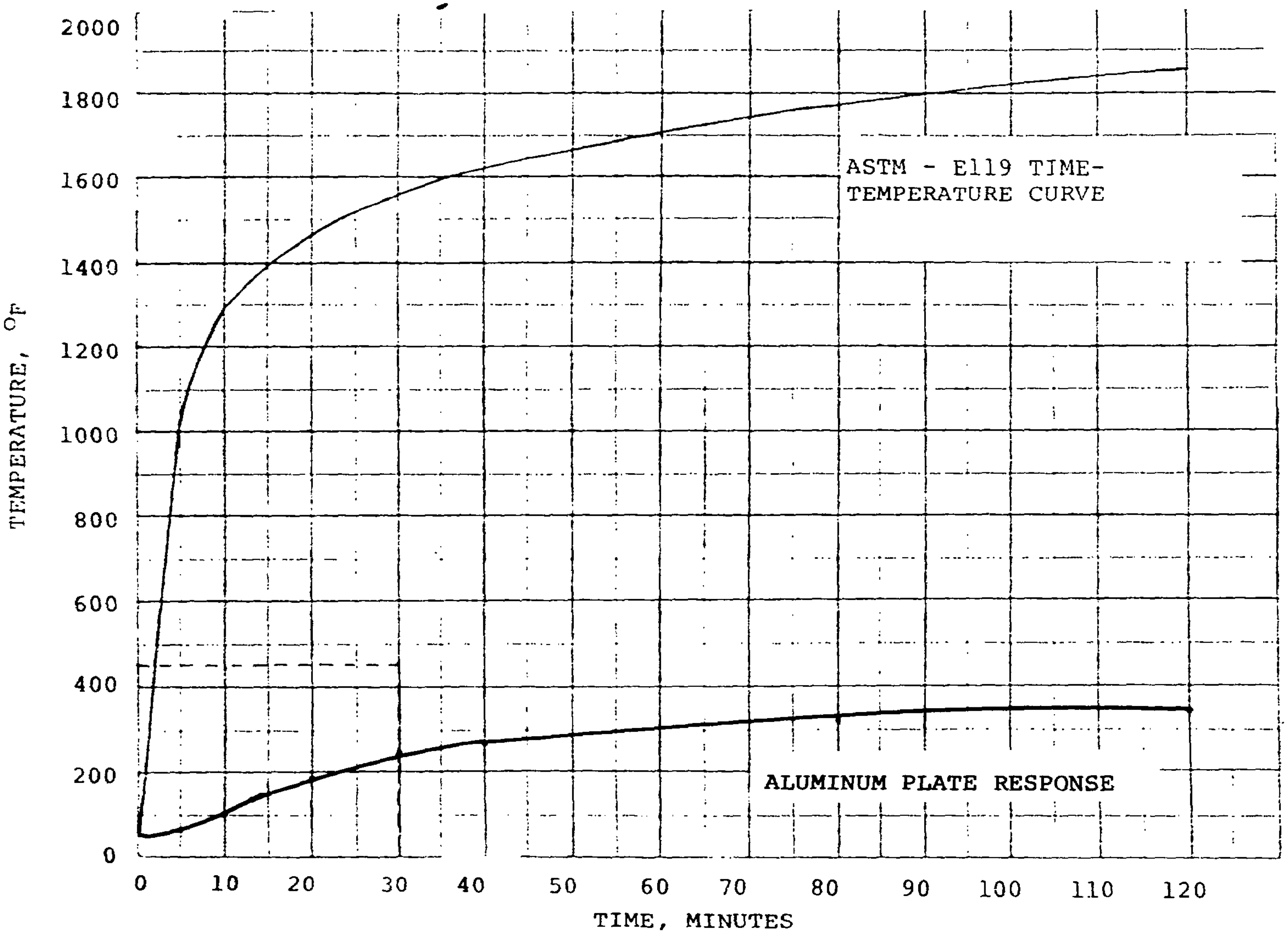
HEATING 5 EVALUATION - INSWOOL -- 1 1/4 inch, 8pcf
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

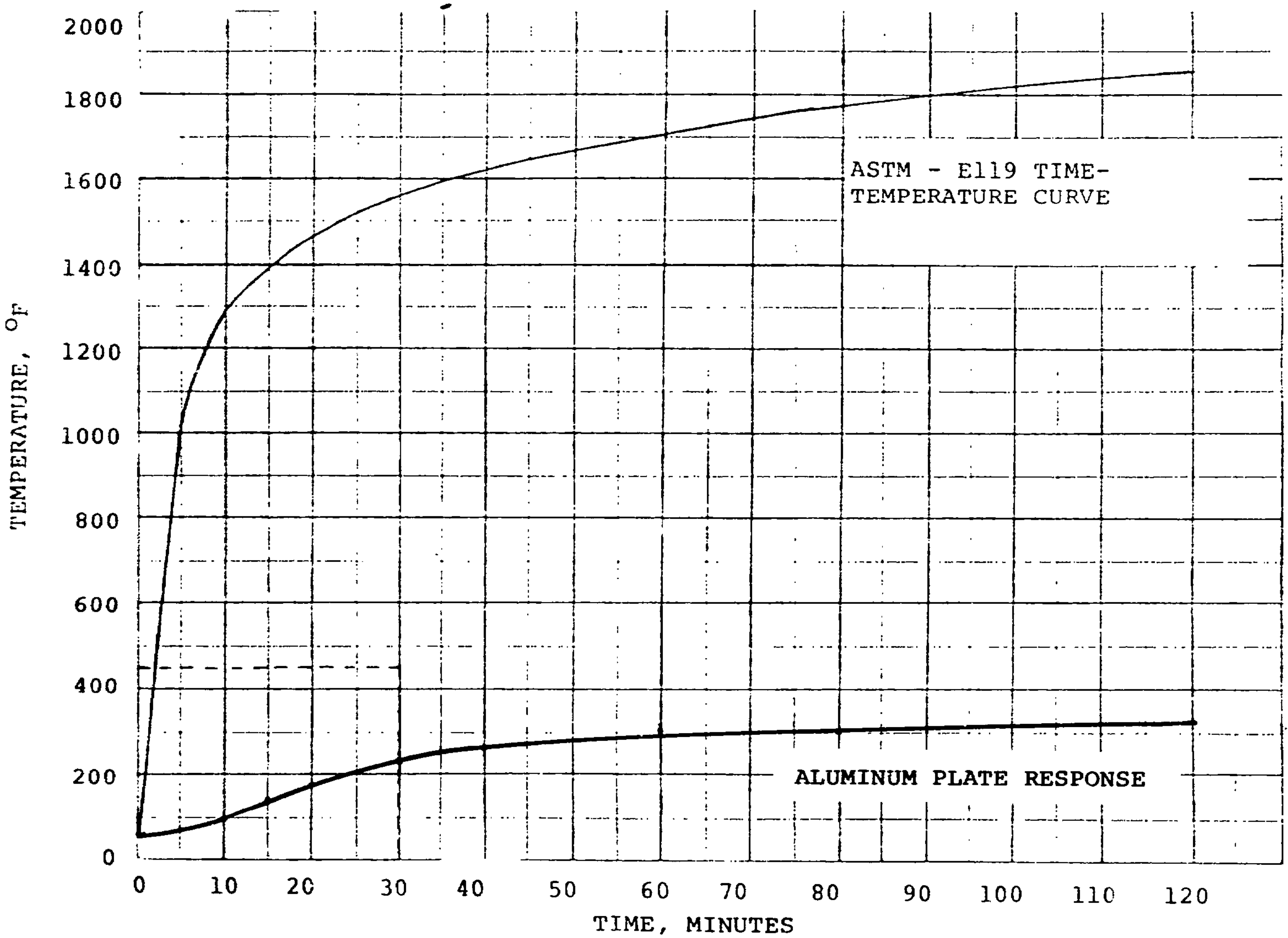
HEATING 5 EVALUATION - LO-CON -- 1 1/2 inch, 6pcf
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

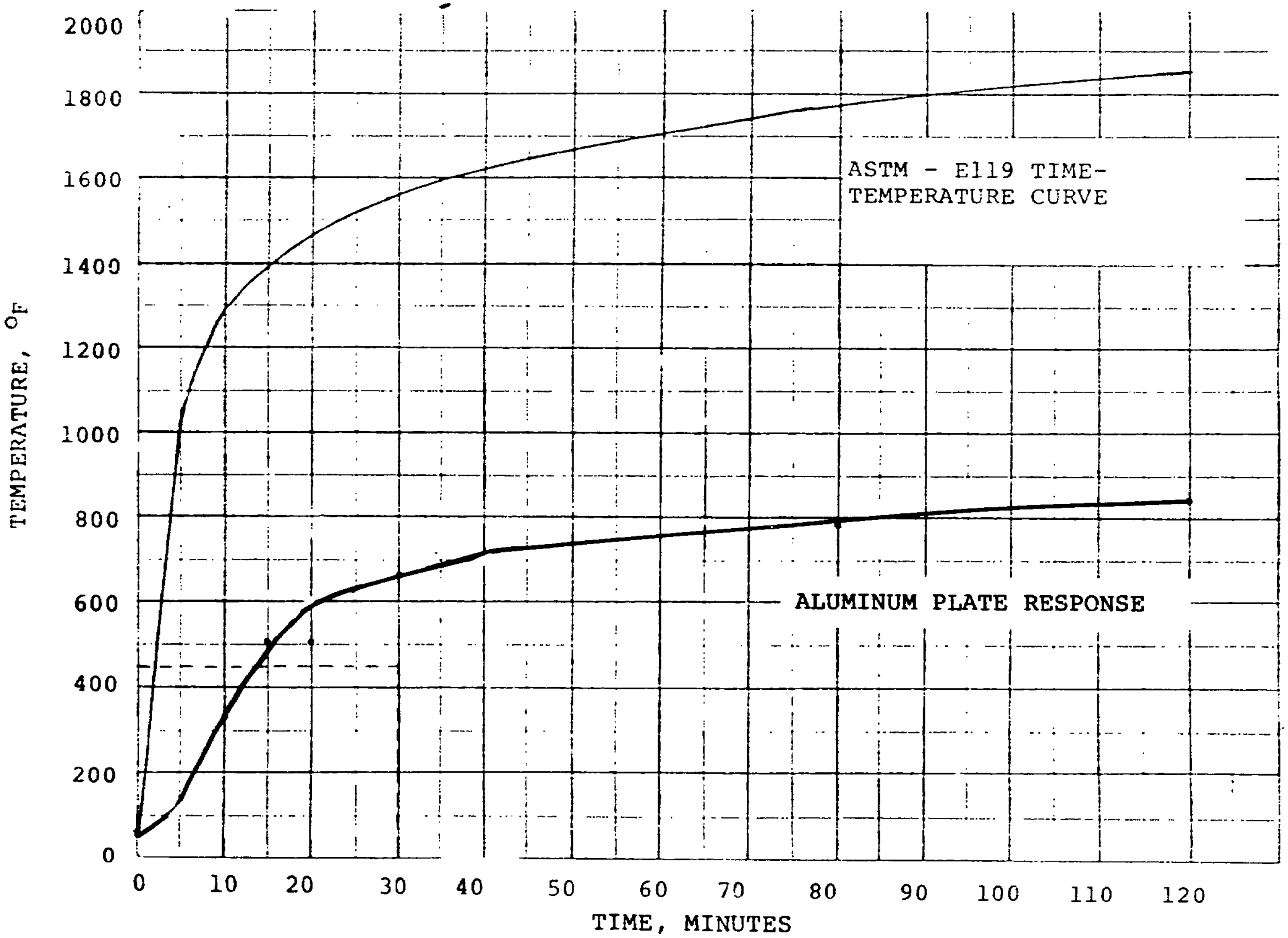
HEATING 5 EVALUATION - **SAFFIL -- 1 1/2 inch, 6pcf**
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

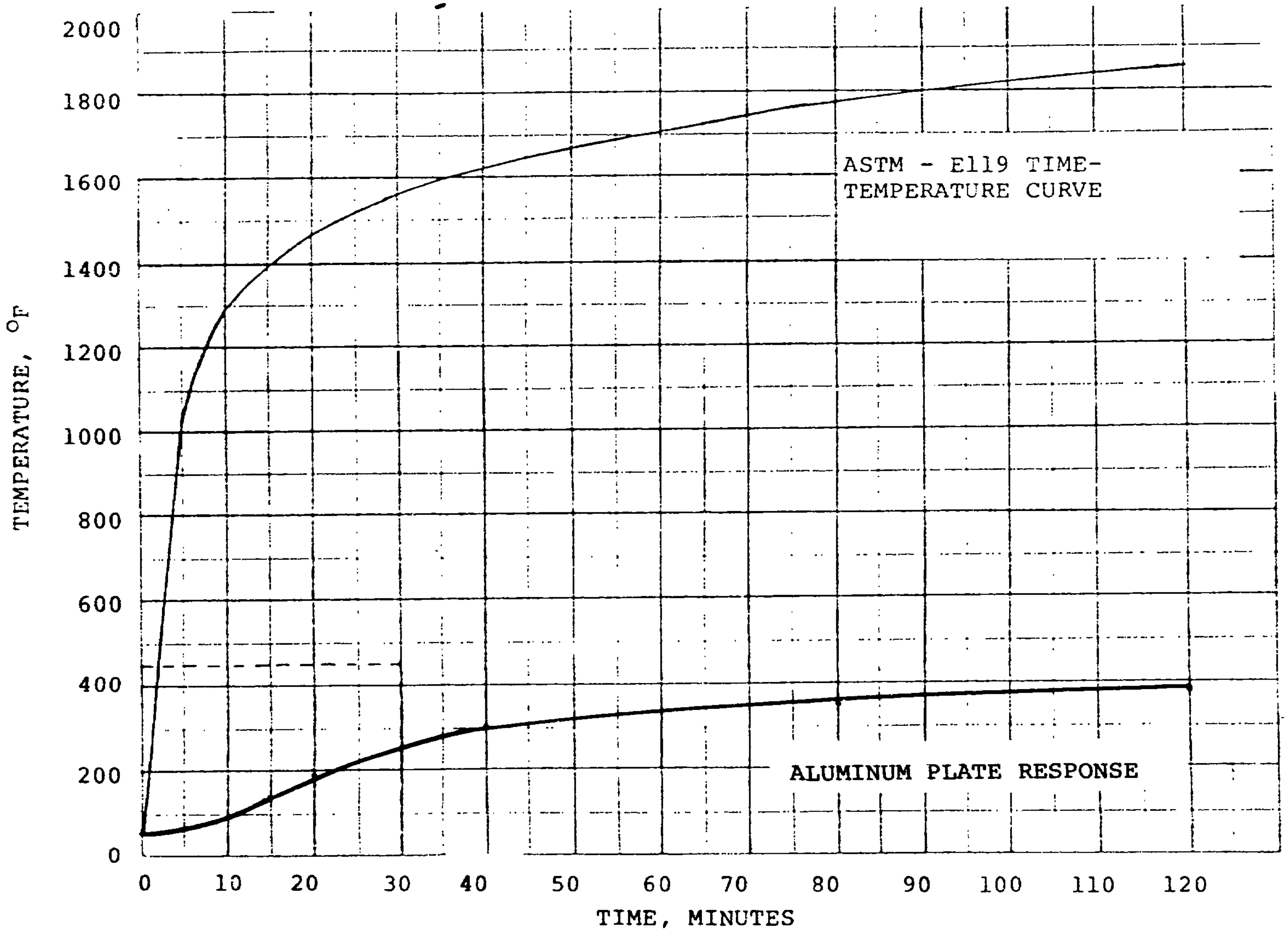
HEATING 5 EVALUATION - **THERMOFLEX II** -- 1/2 inch, 12pcf
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

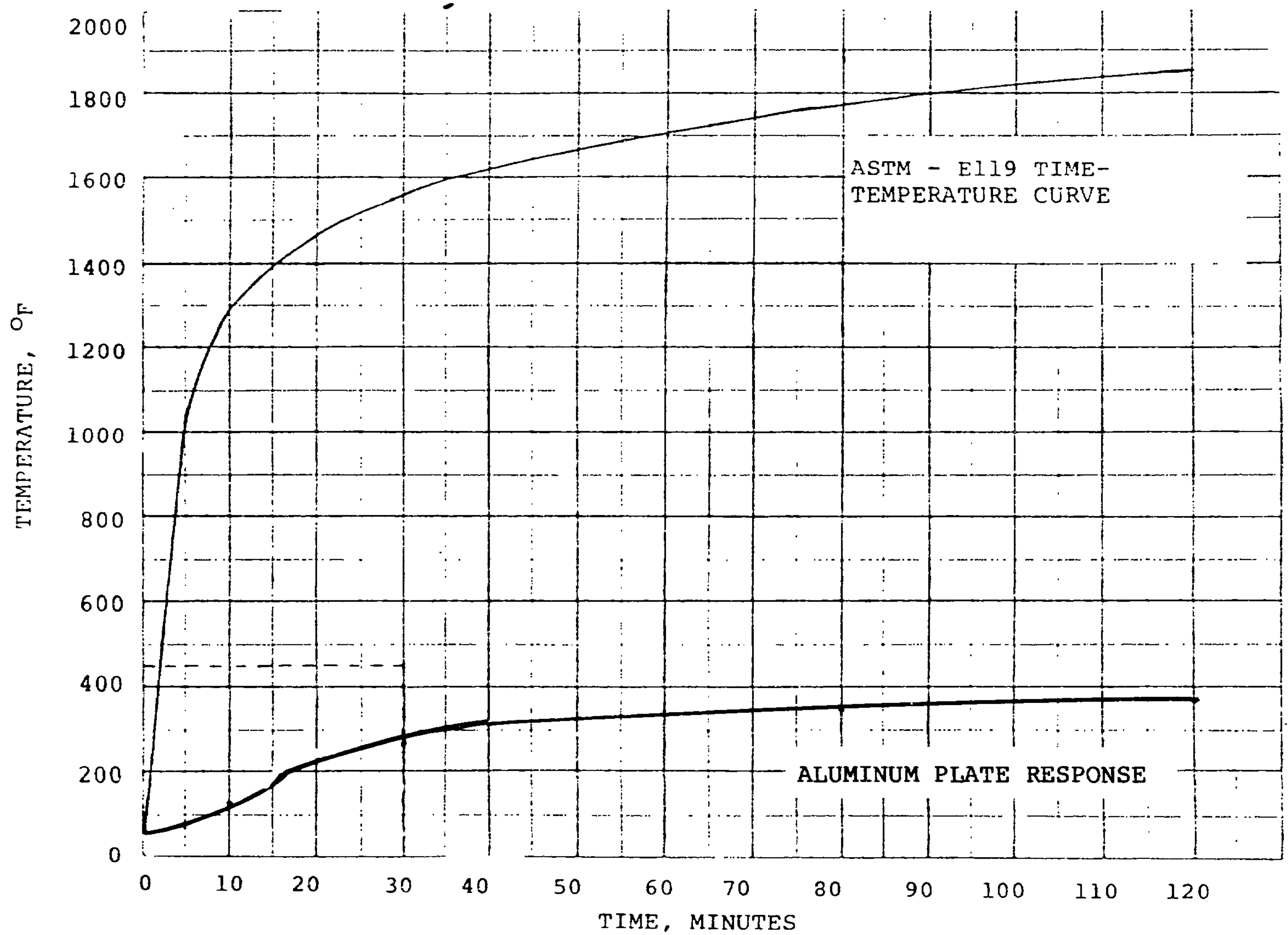
HEATING 5 EVALUATION - **CERAFORM 126 -- 1 inch, 18.5pcf**
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

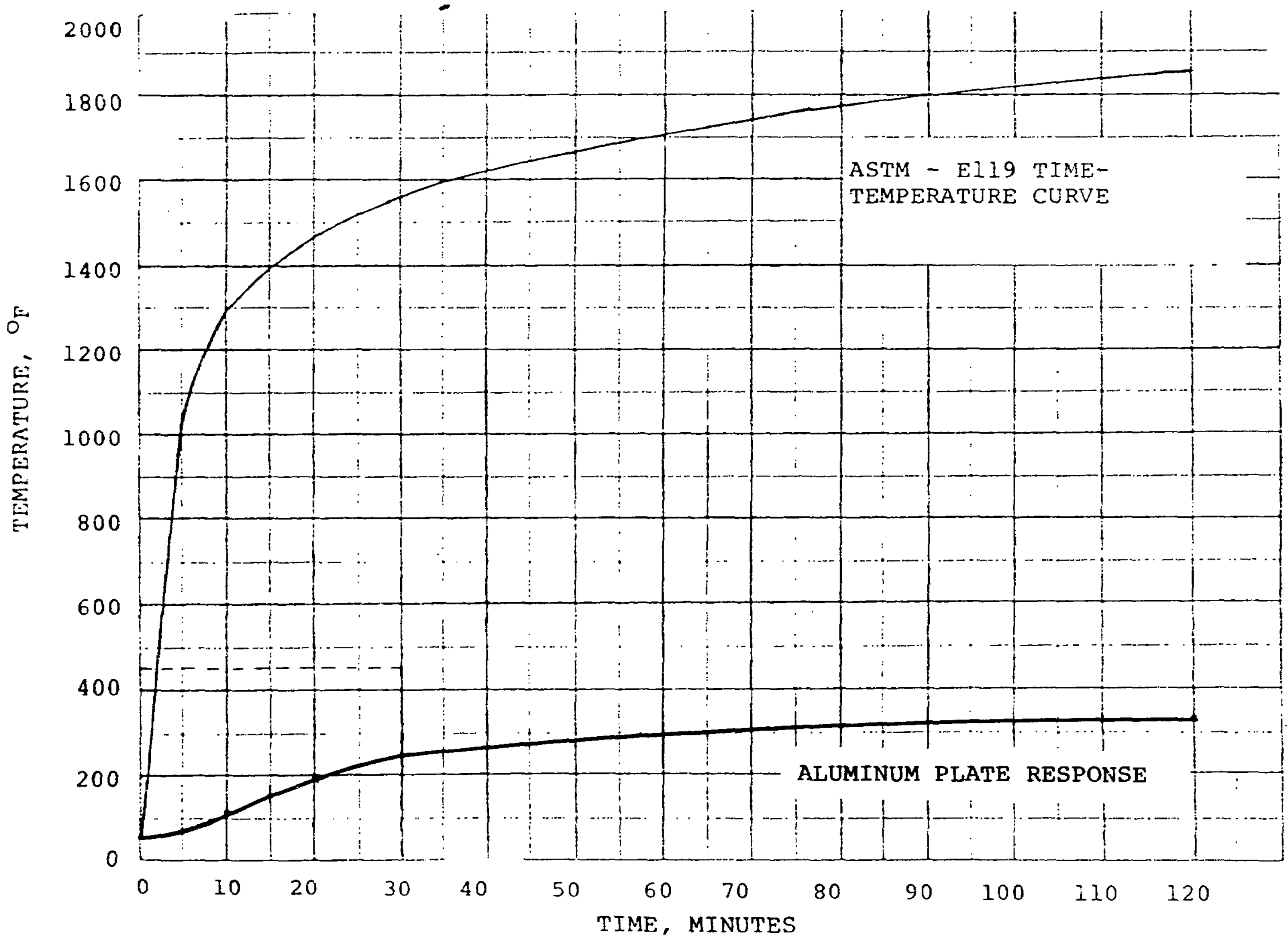
HEATING 5 EVALUATION - **Q-FIBER -- 1 inch, 6pcf**
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

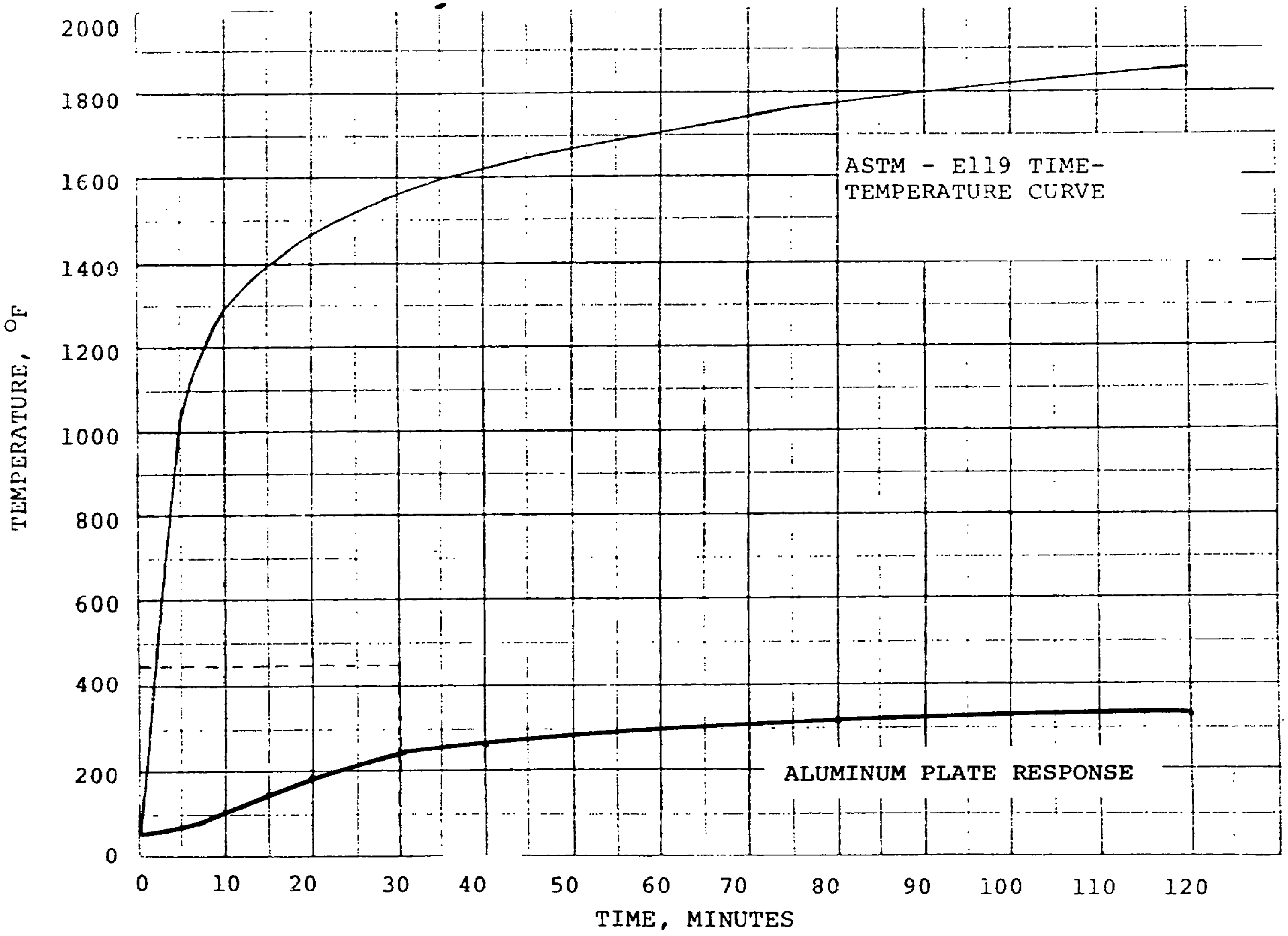
HEATING 5 EVALUATION - Q-FIBER -- 1 1/4 inch, 6pcf
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

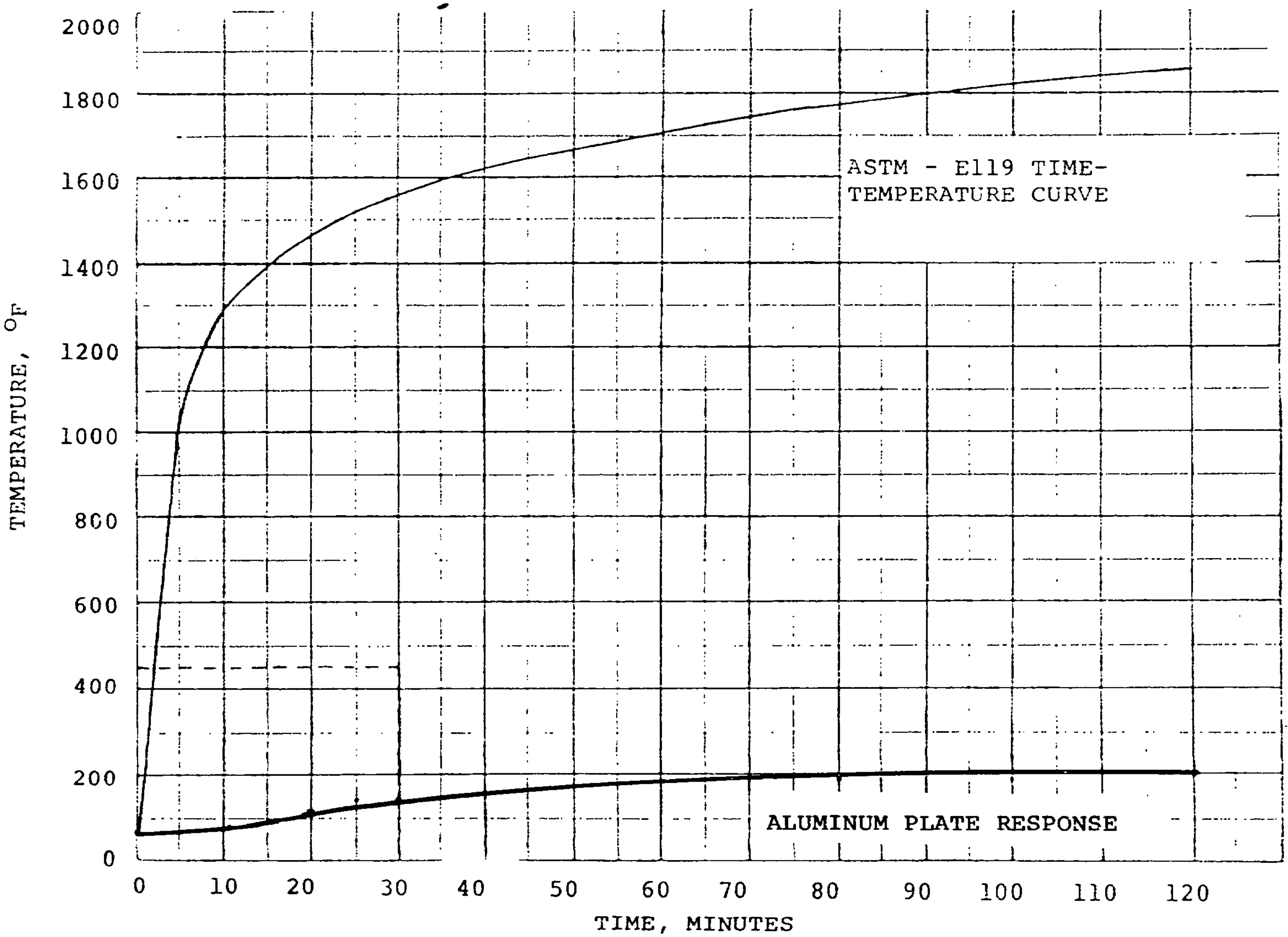
HEATING 5 EVALUATION - MICROLITE B -- 1 1/2 inch, 4.5pcf
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

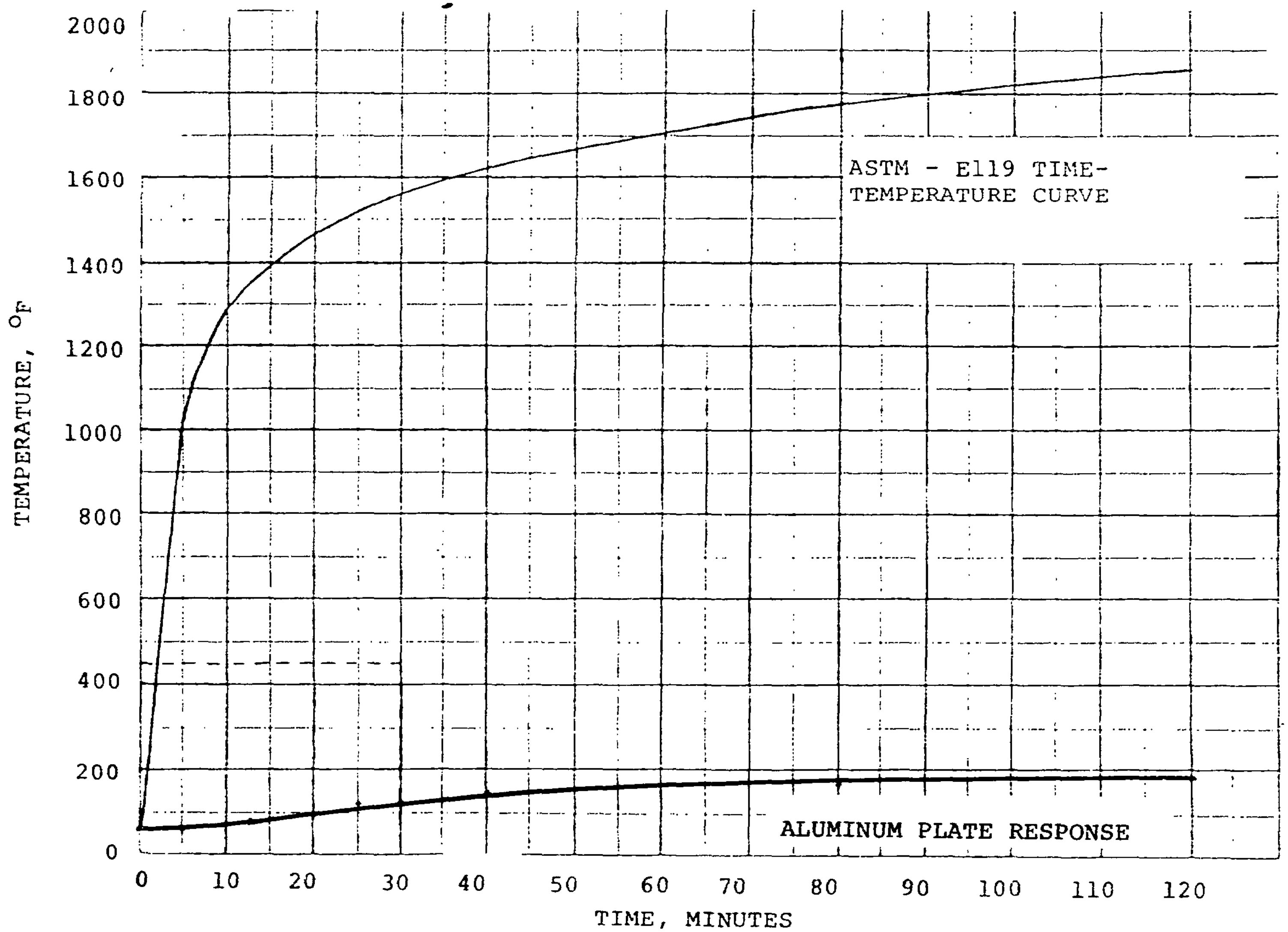
HEATING 5 EVALUATION - MIN-K 1301 -- 3/4 inch, 20pcf
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

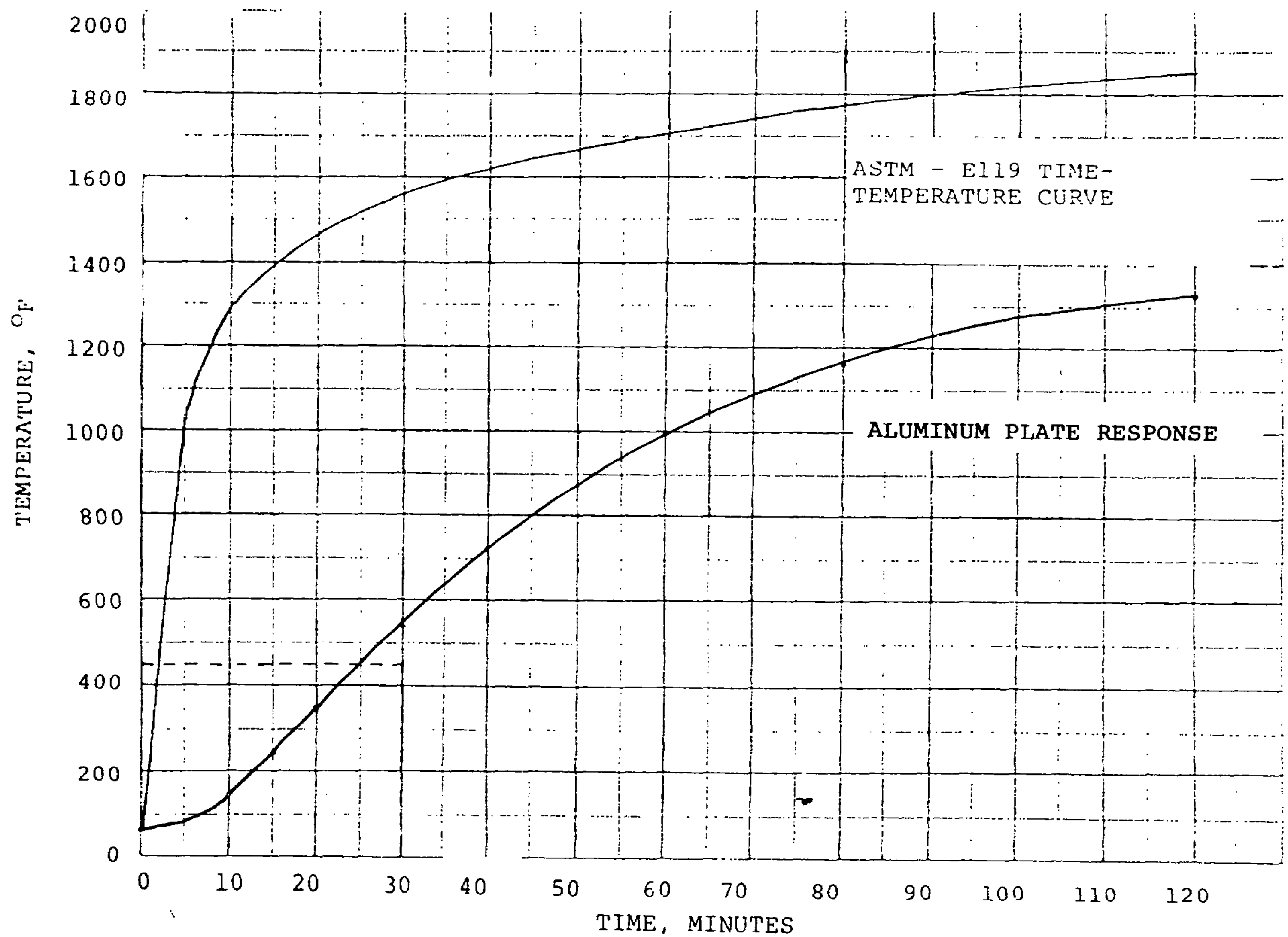
HEATING 5 EVALUATION - **MIN-K 2000 -- 1 inch, 20pcf**
SINGLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

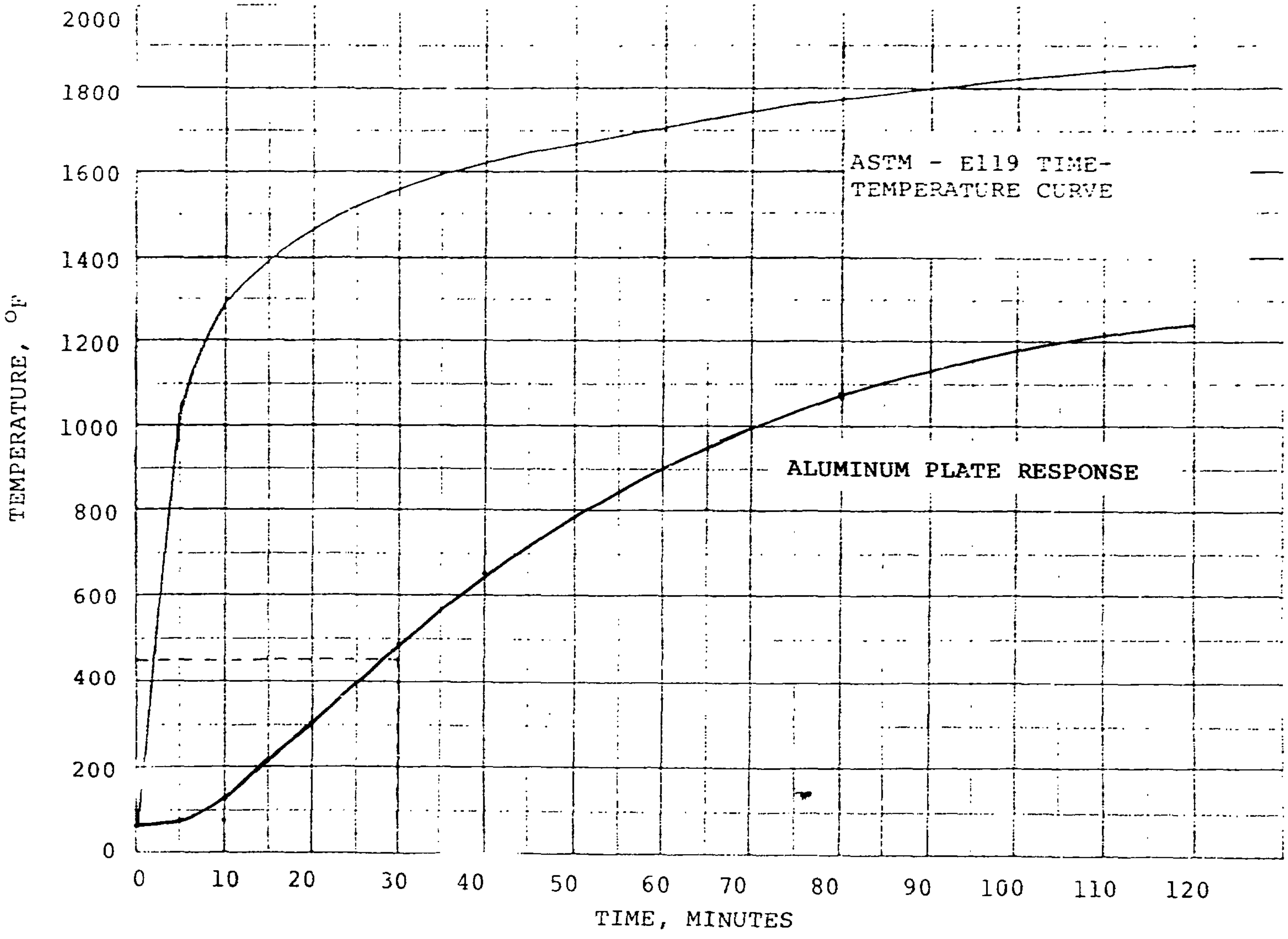
HEATING 5 EVALUATION - **CERAFELT -- 1 in. 4pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

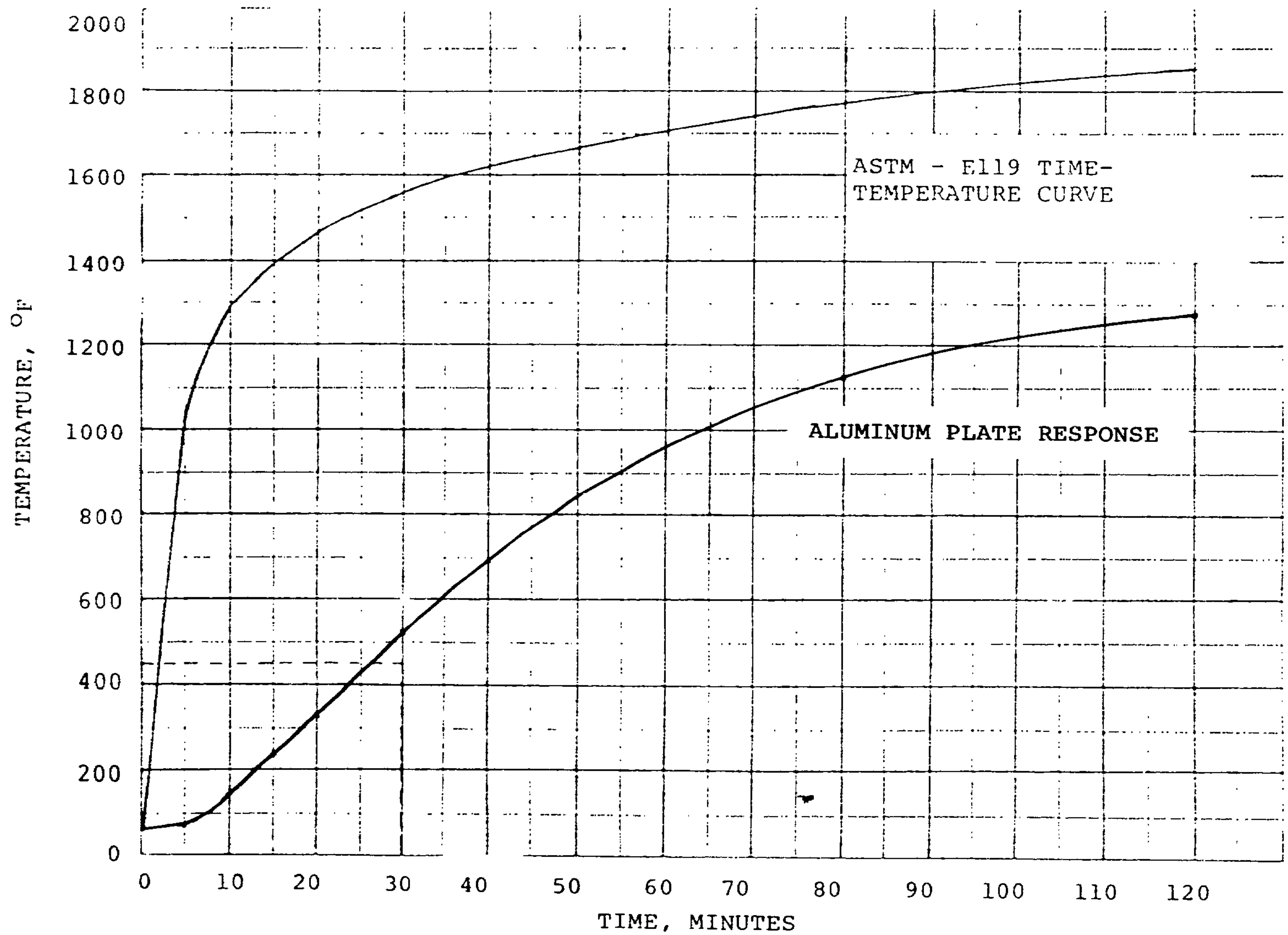
HEATING 5 EVALUATION - **CERAFIBER -- 1 1/2 inch, 6pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

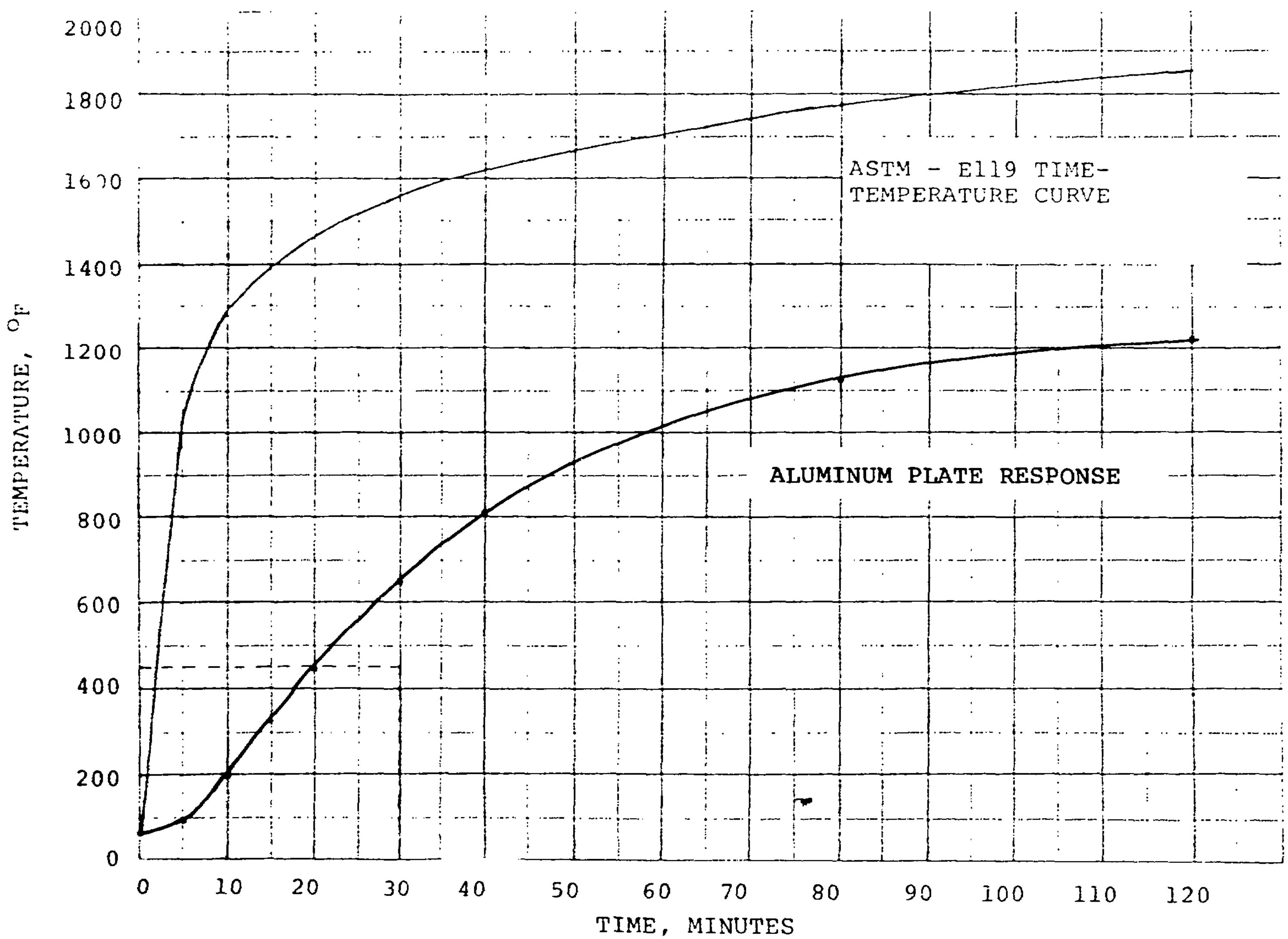
HEATING 5 EVALUATION - **CERAFELT -- 1 inch 8pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

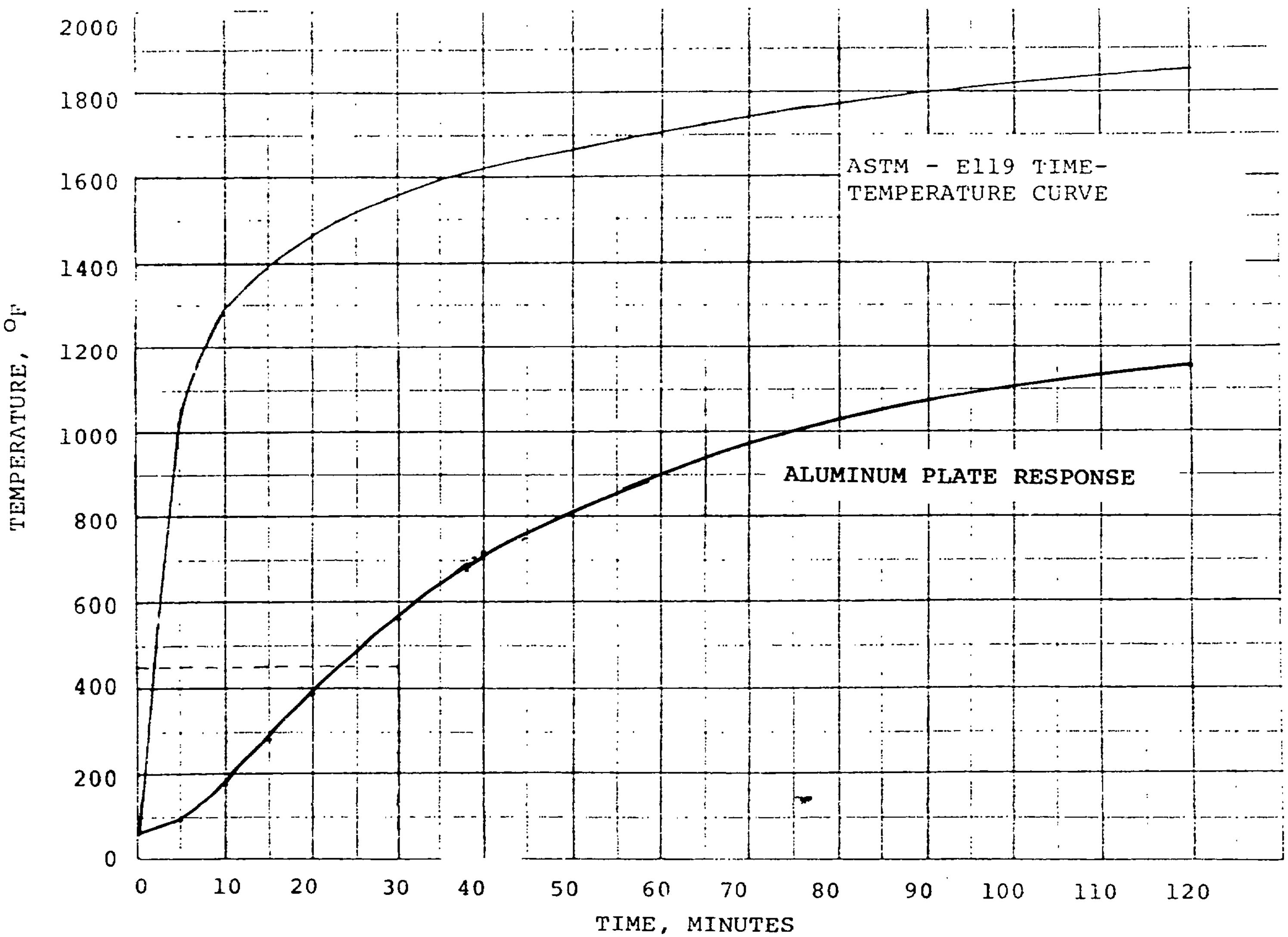
HEATING 5 EVALUATION - **LIGHT-WEIGHT FLEXIBLE MIN-K -- 3/8 inch, 10pcf Core**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

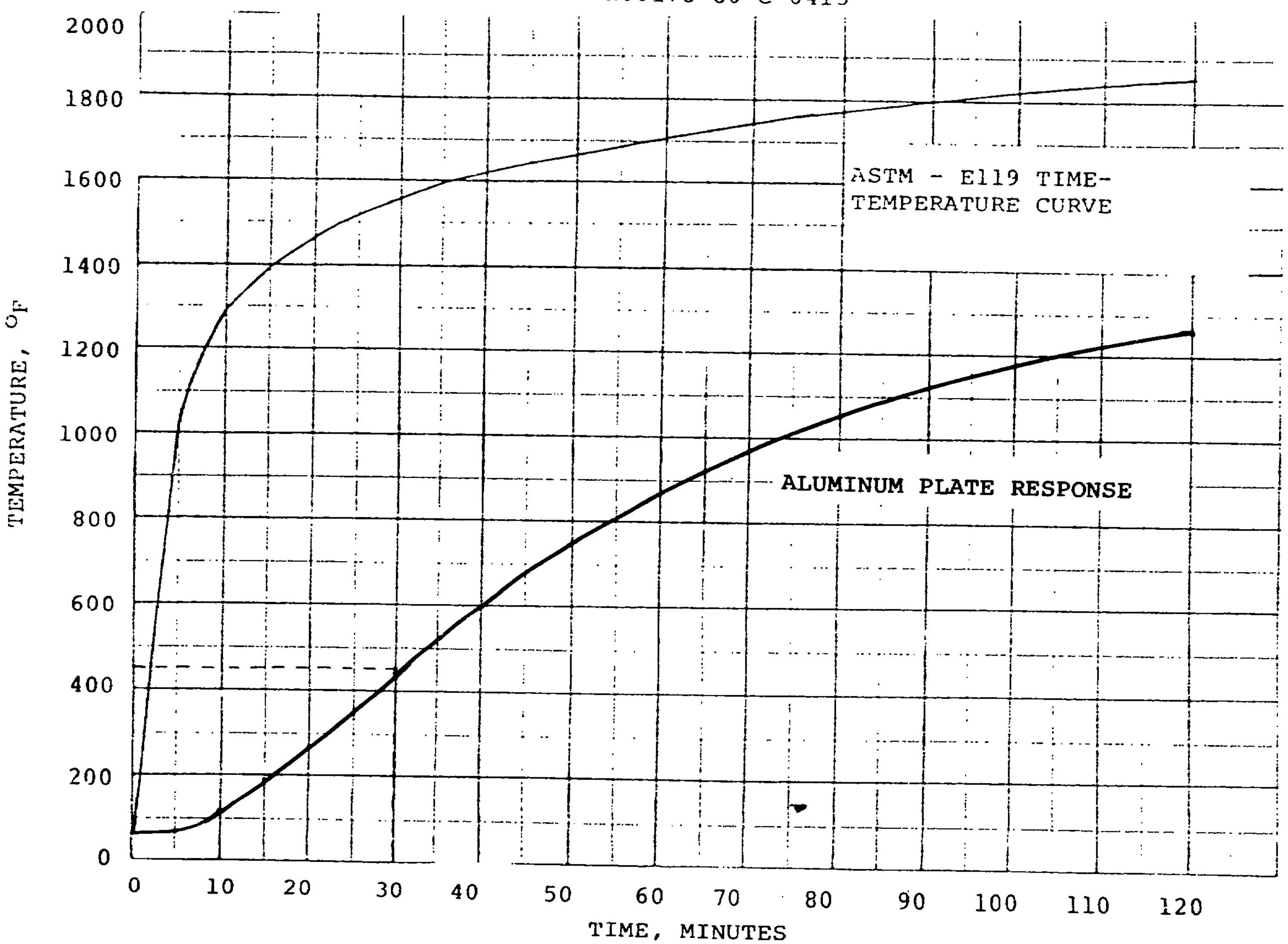
HEATING 5 EVALUATION - **LIGHTWEIGHT FLEXIBLE MIN-K -- 1/2 inch, 8pcf Core**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

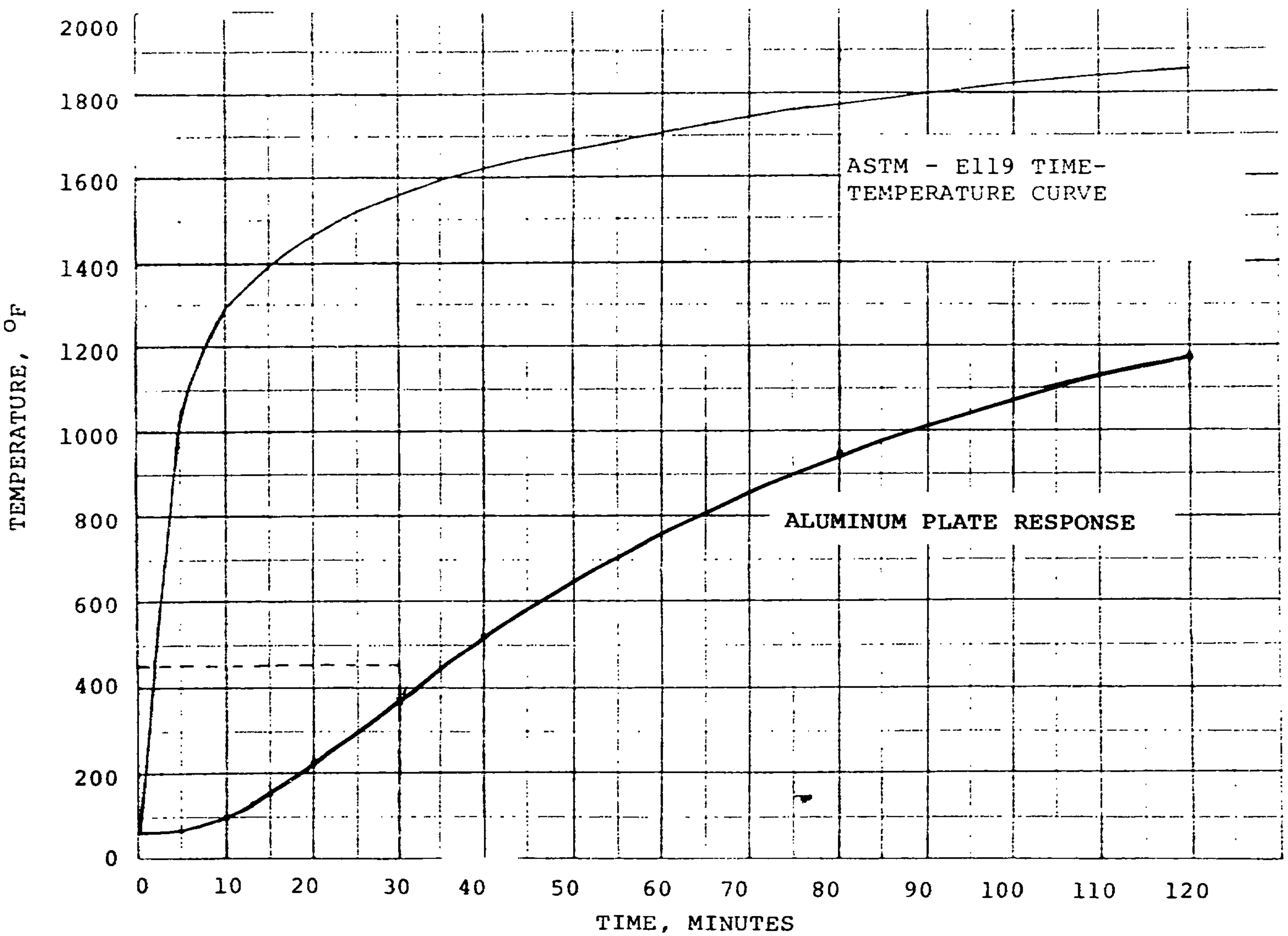
HEATING 5 EVALUATION - **CERAFELT -- 2 inch, 4pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

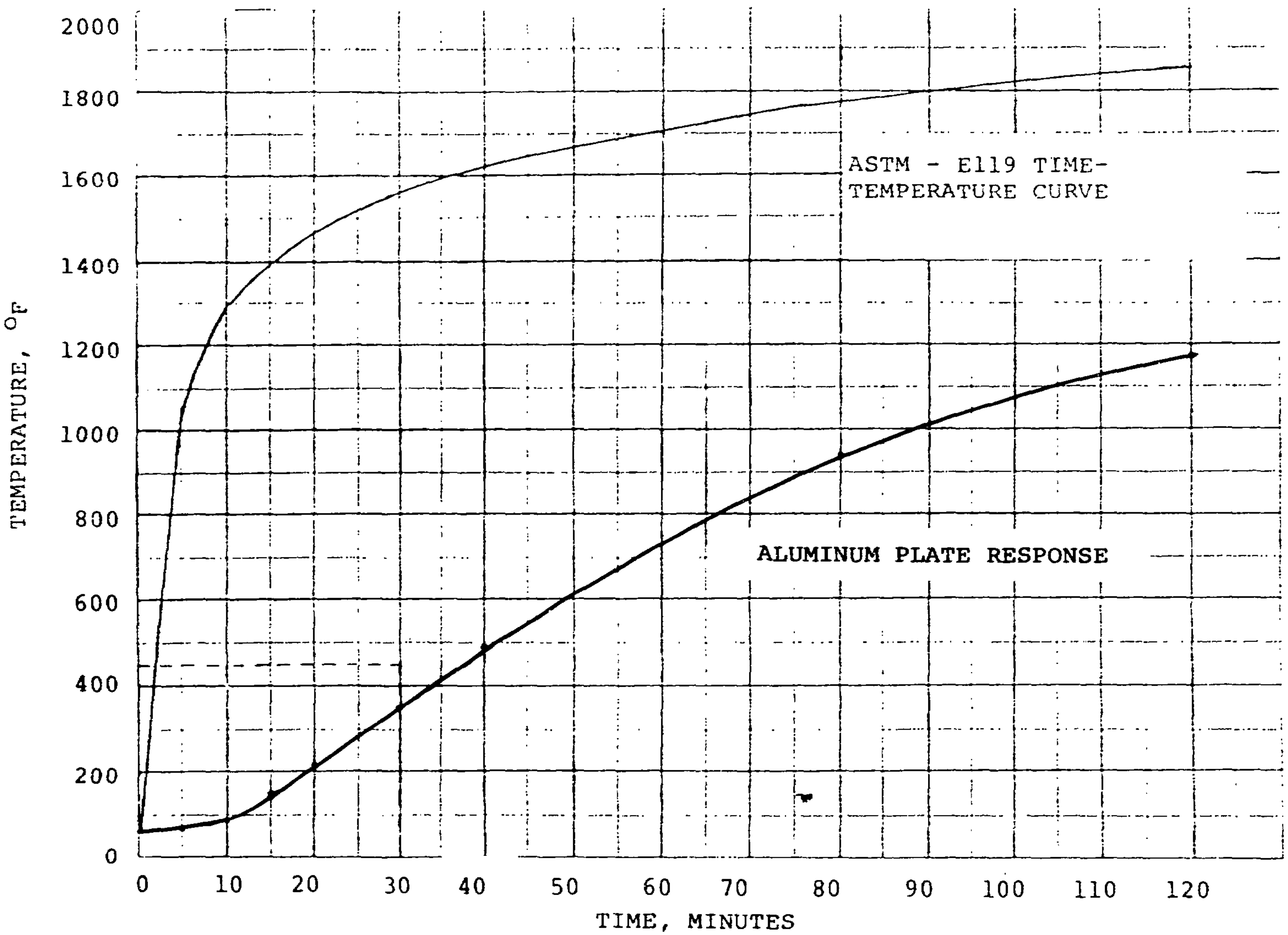
HEATING 5 EVALUATION - **CERAFIBER -- 2-inch, 6 pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

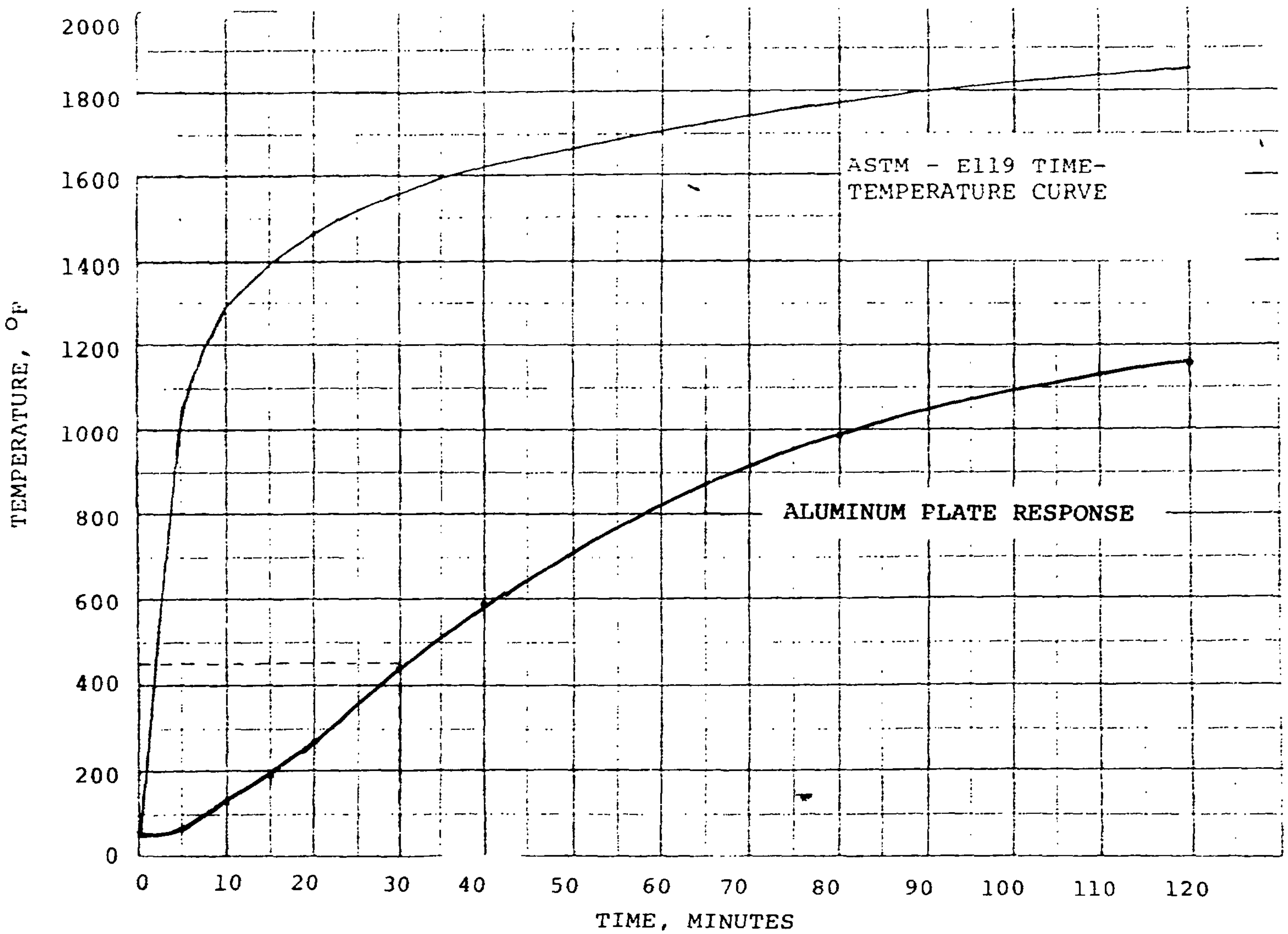
HEATING 5 EVALUATION - **KAOWOOL -- 1 1/2 inch, 8pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

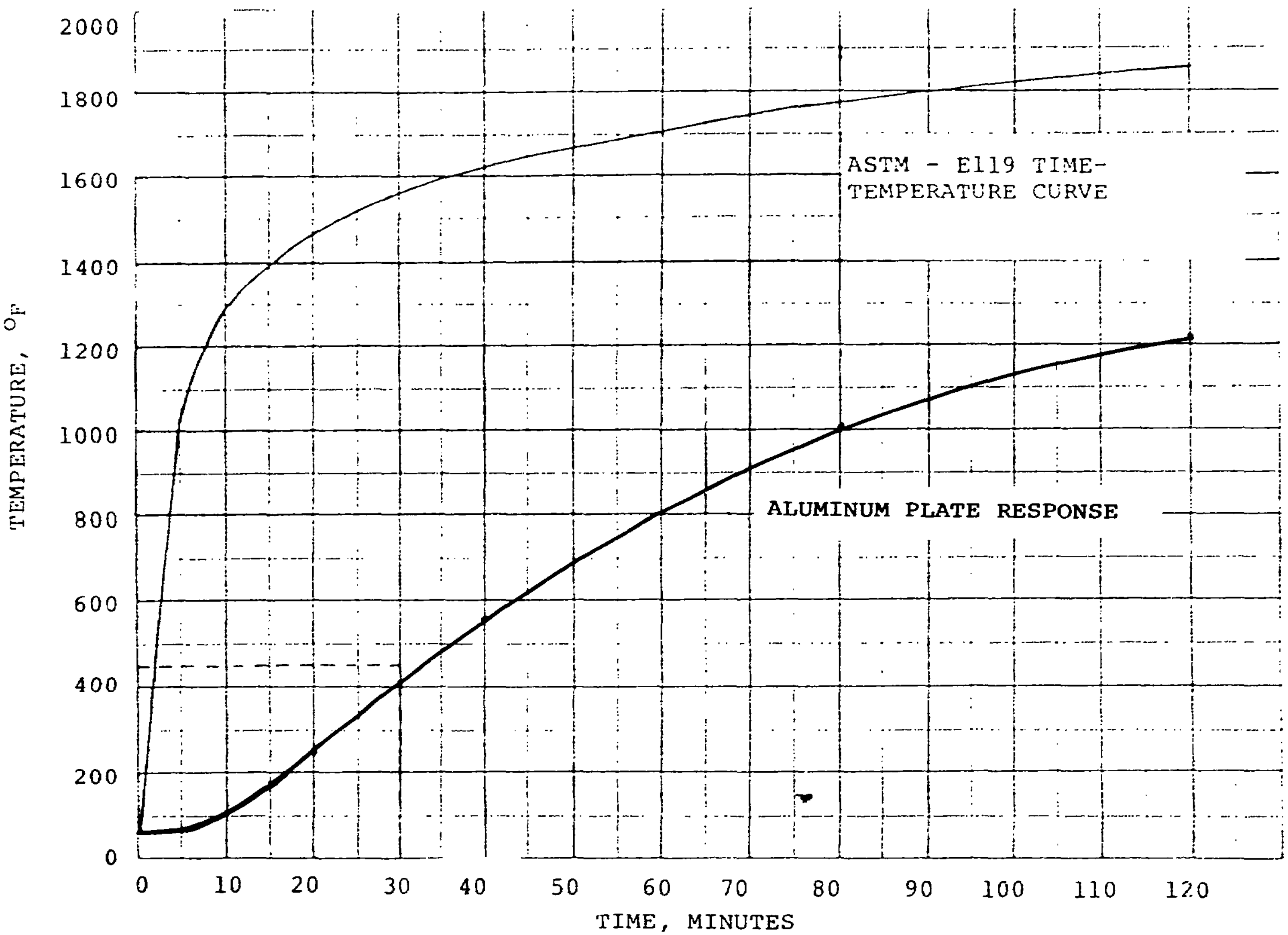
HEATING 5 EVALUATION - **INSWOOL -- 1 1/4 inch, 8pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

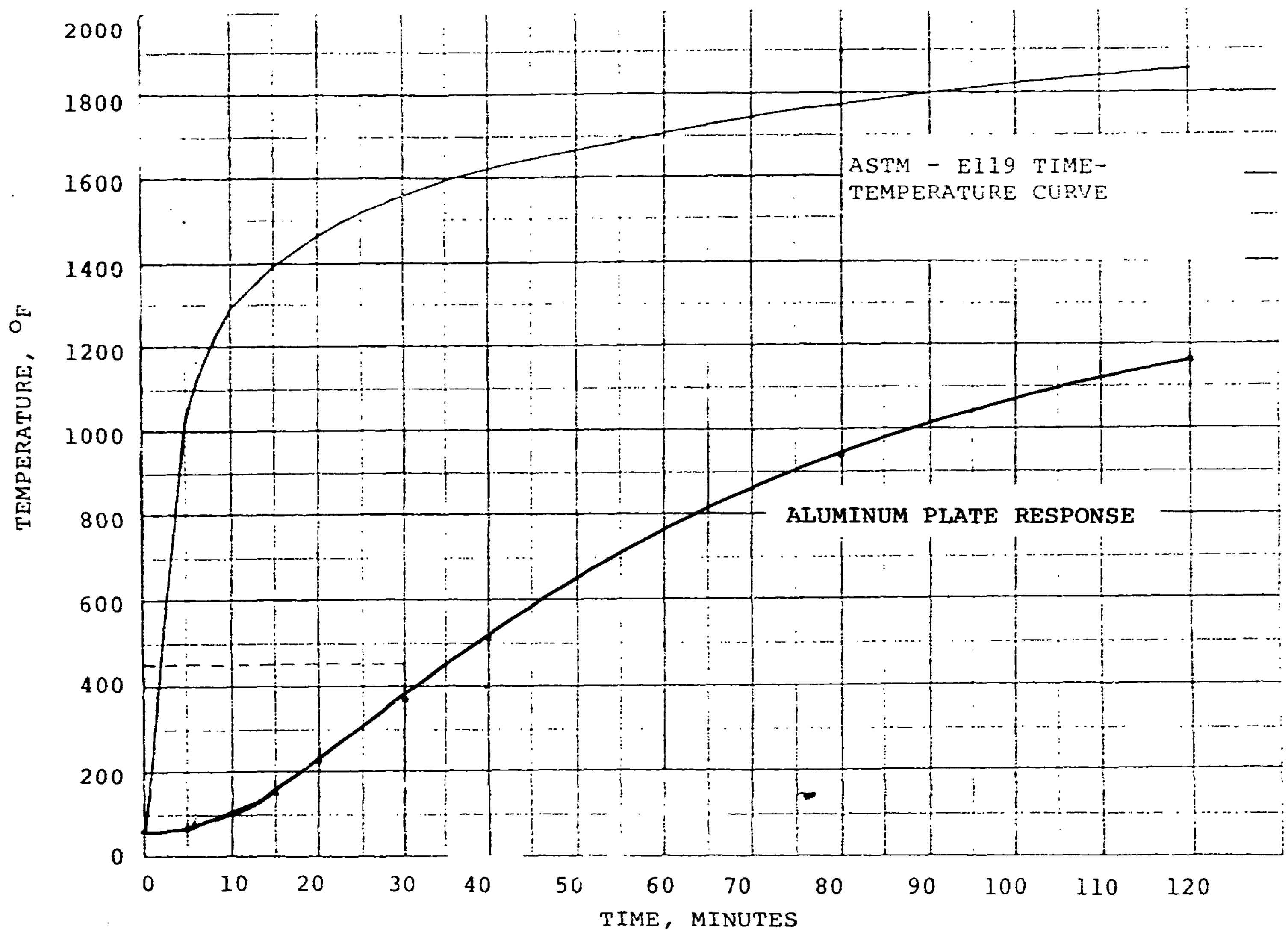
HEATING 5 EVALUATION - **LO CON -- 1 1/2 inch, 6 pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

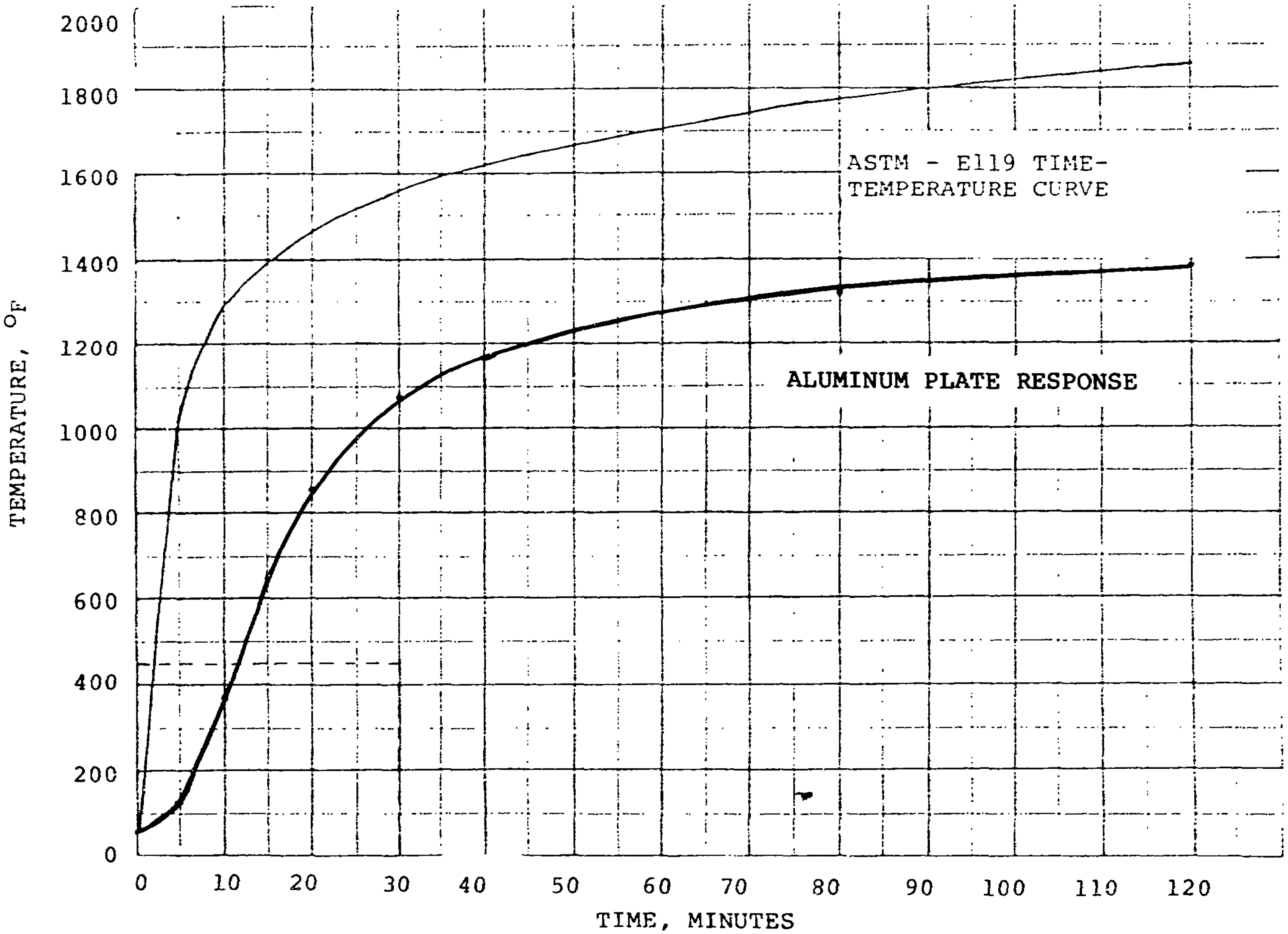
HEATING 5 EVALUATION - **SAFFIL -- 1 1/2 inch, 6 pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

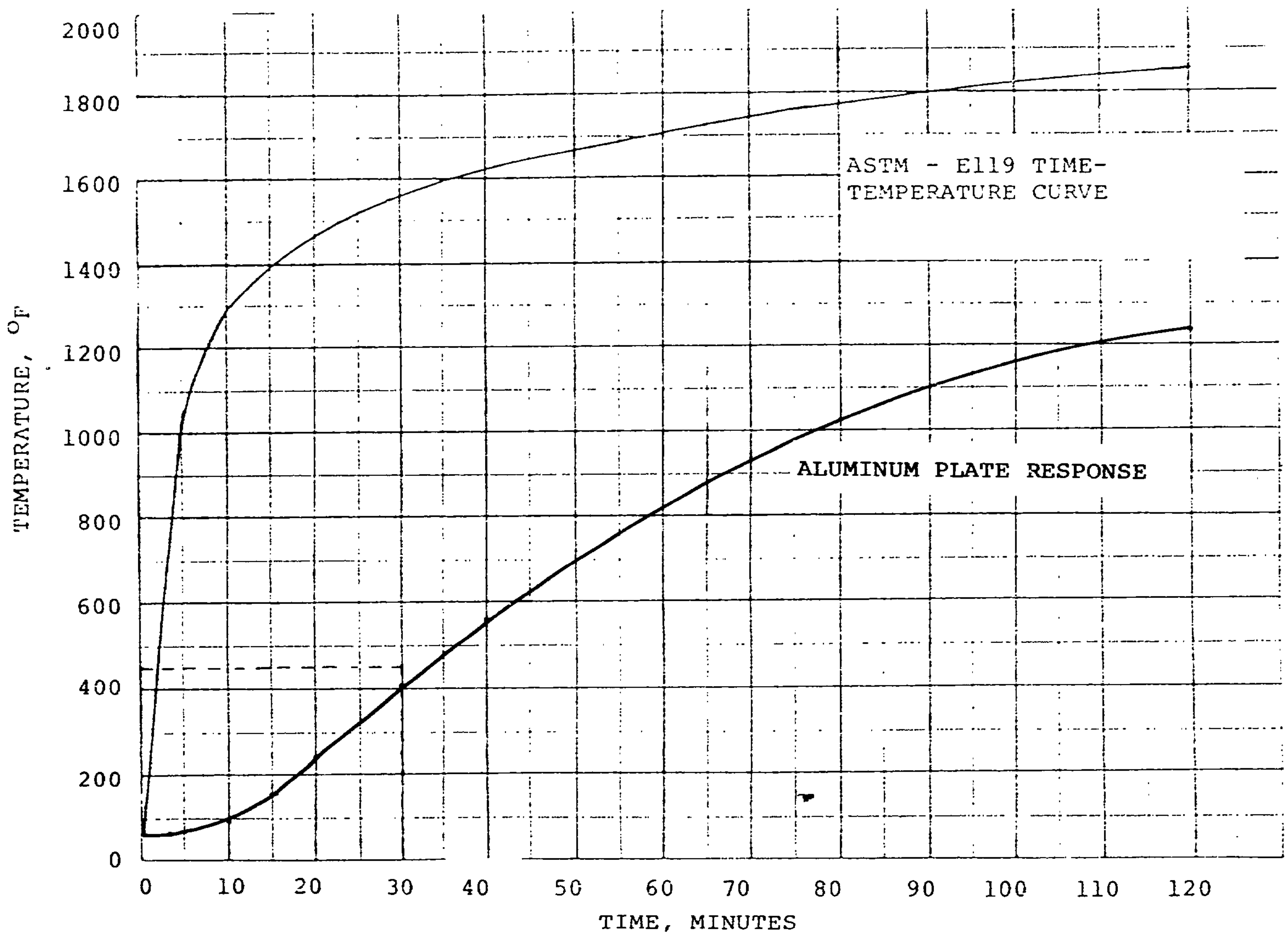
HEATING 5 EVALUATION - **THERMOFLEX II -- 1/2 inch, 12pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

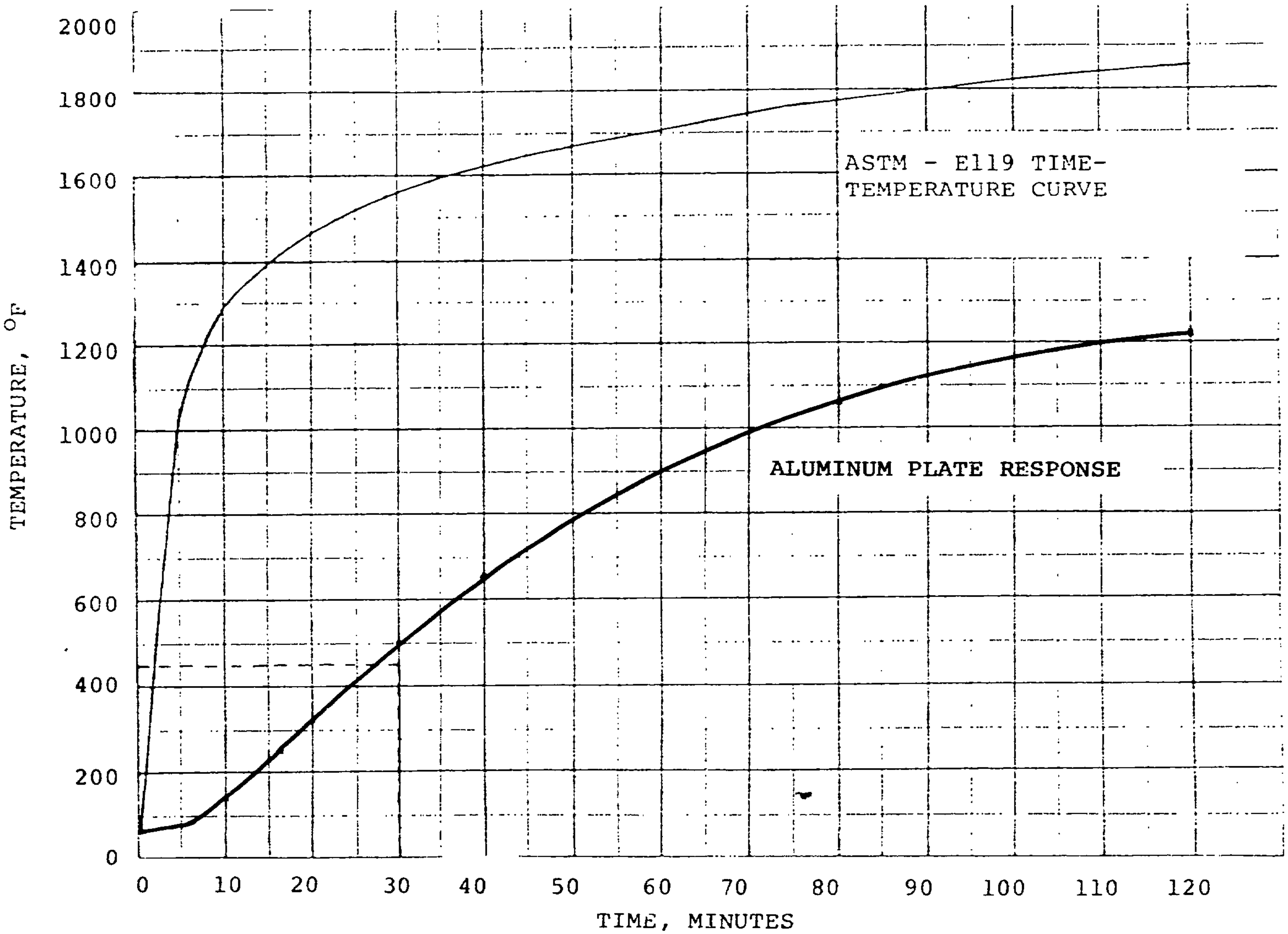
HEATING 5 EVALUATION - **CERAFORM 126 -- 1 inch, 18.5pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

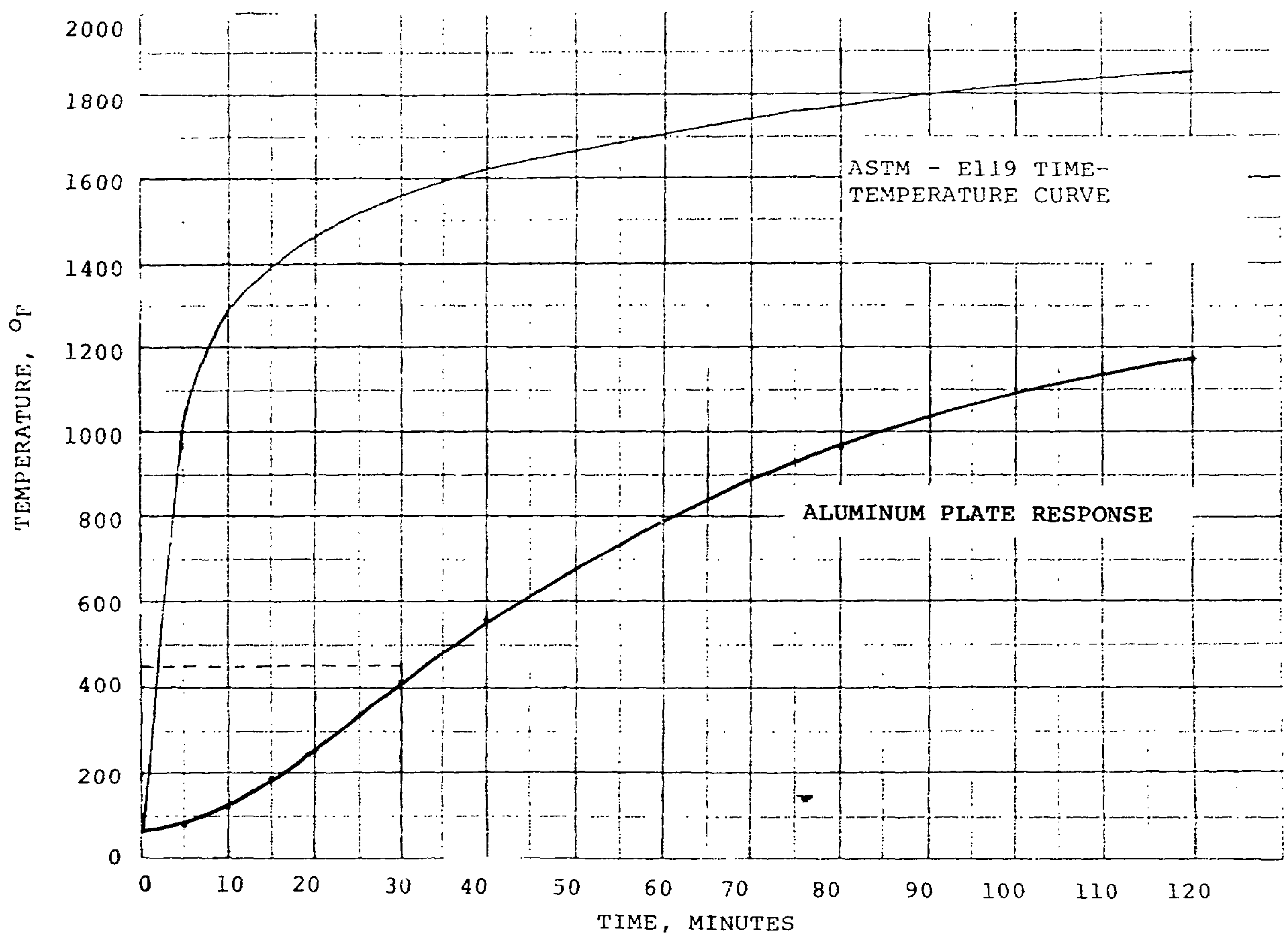
HEATING 5 EVALUATION - Q-FIBER -- 1 inch, 6pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

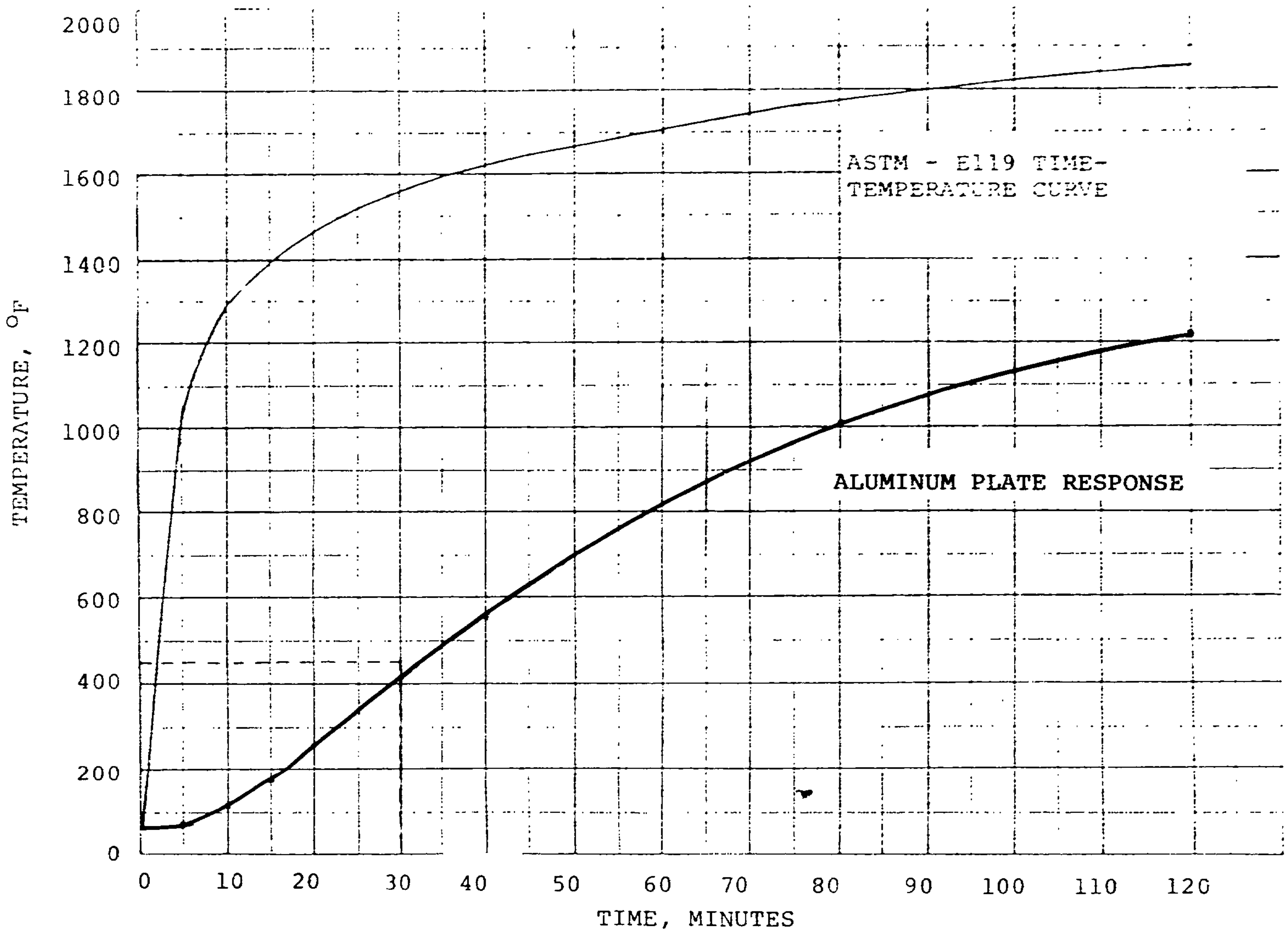
HEATING 5 EVALUATION - **Q-FIBER -- 1 1/4 inch, 6pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

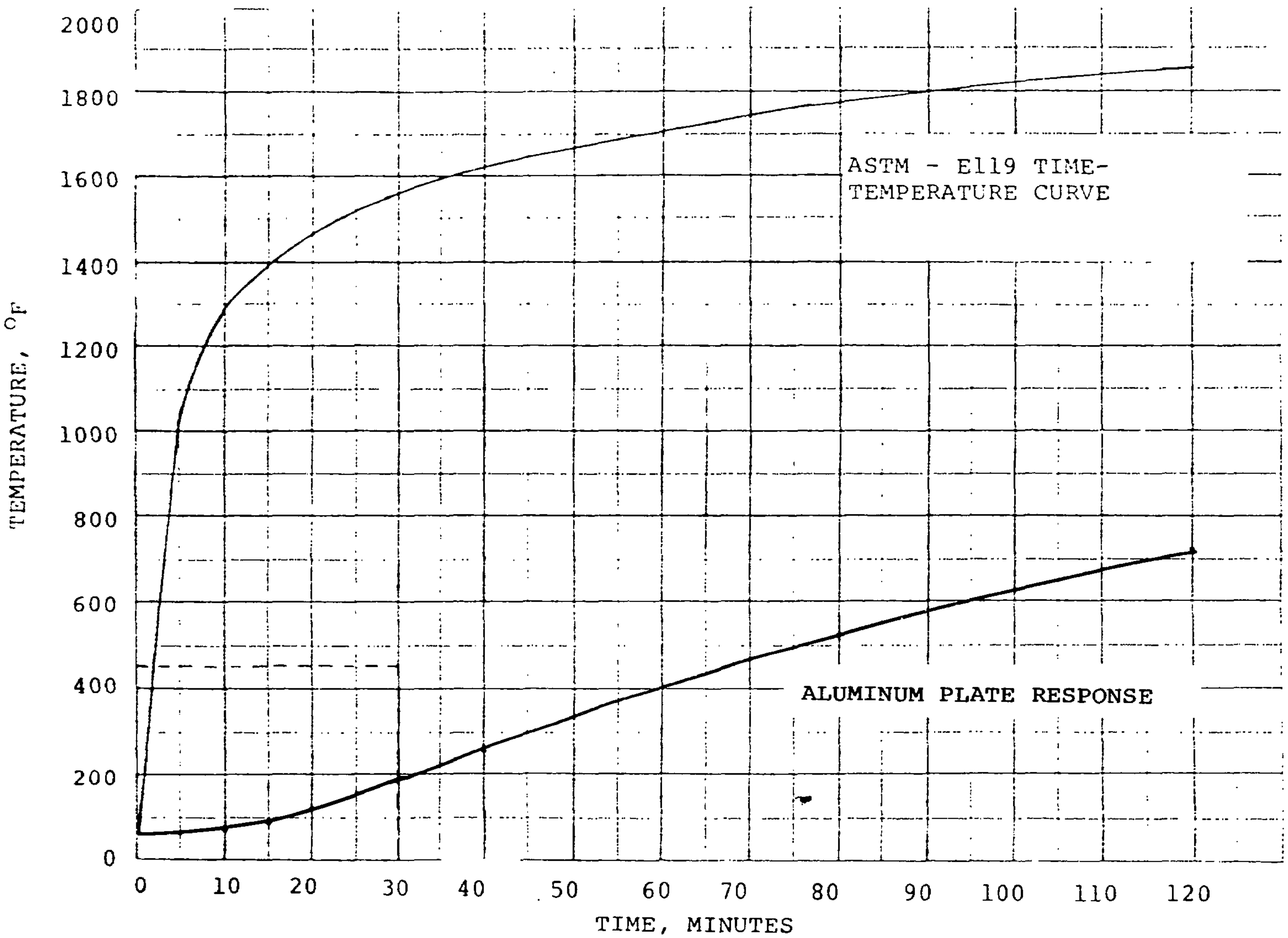
HEATING 5 EVALUATION - **MICROLITE B -- 1 1/2 inch, 4.5pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

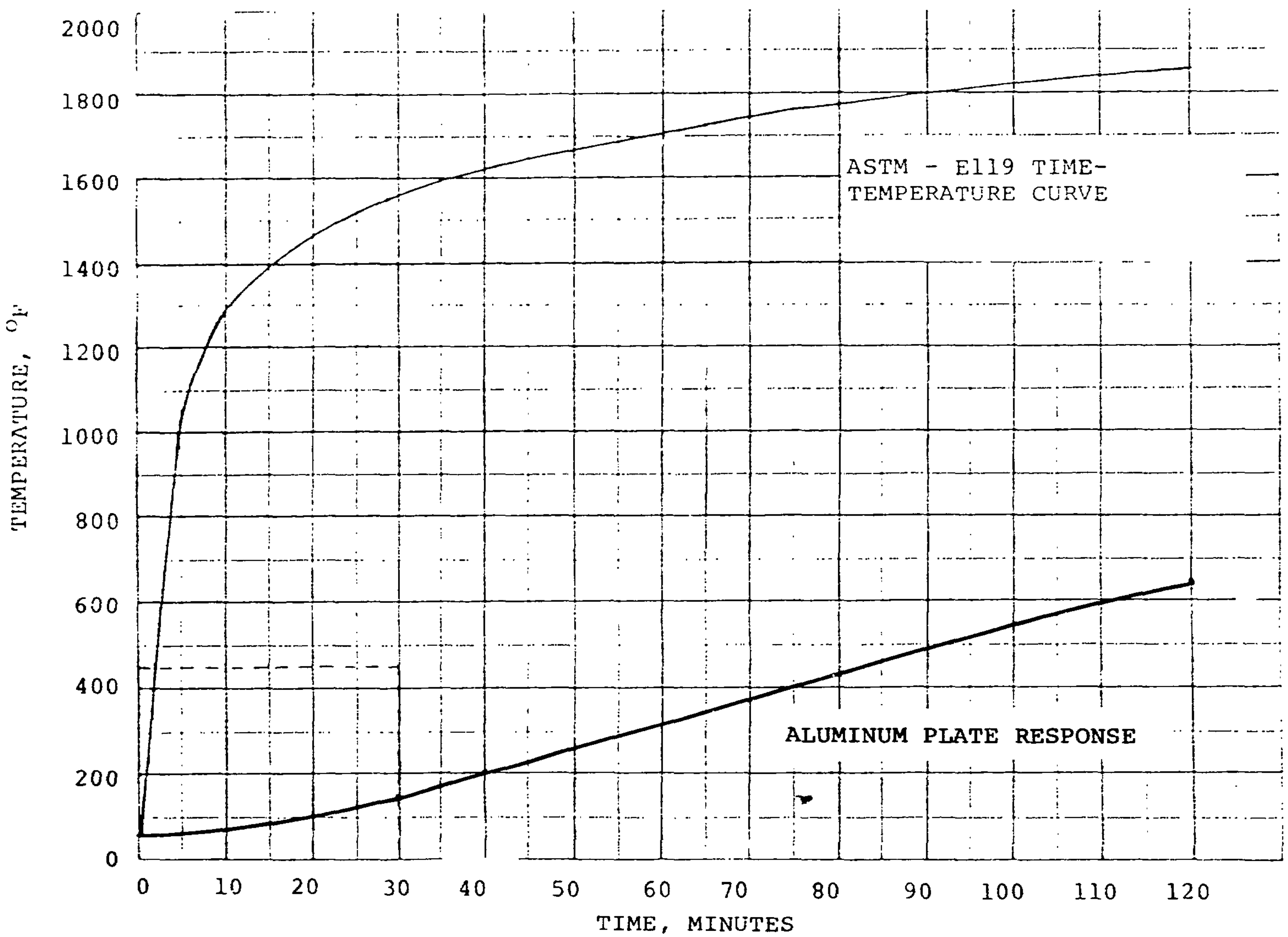
HEATING 5 EVALUATION - **MIN-K 1301 -- 3/4 inch, 20pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

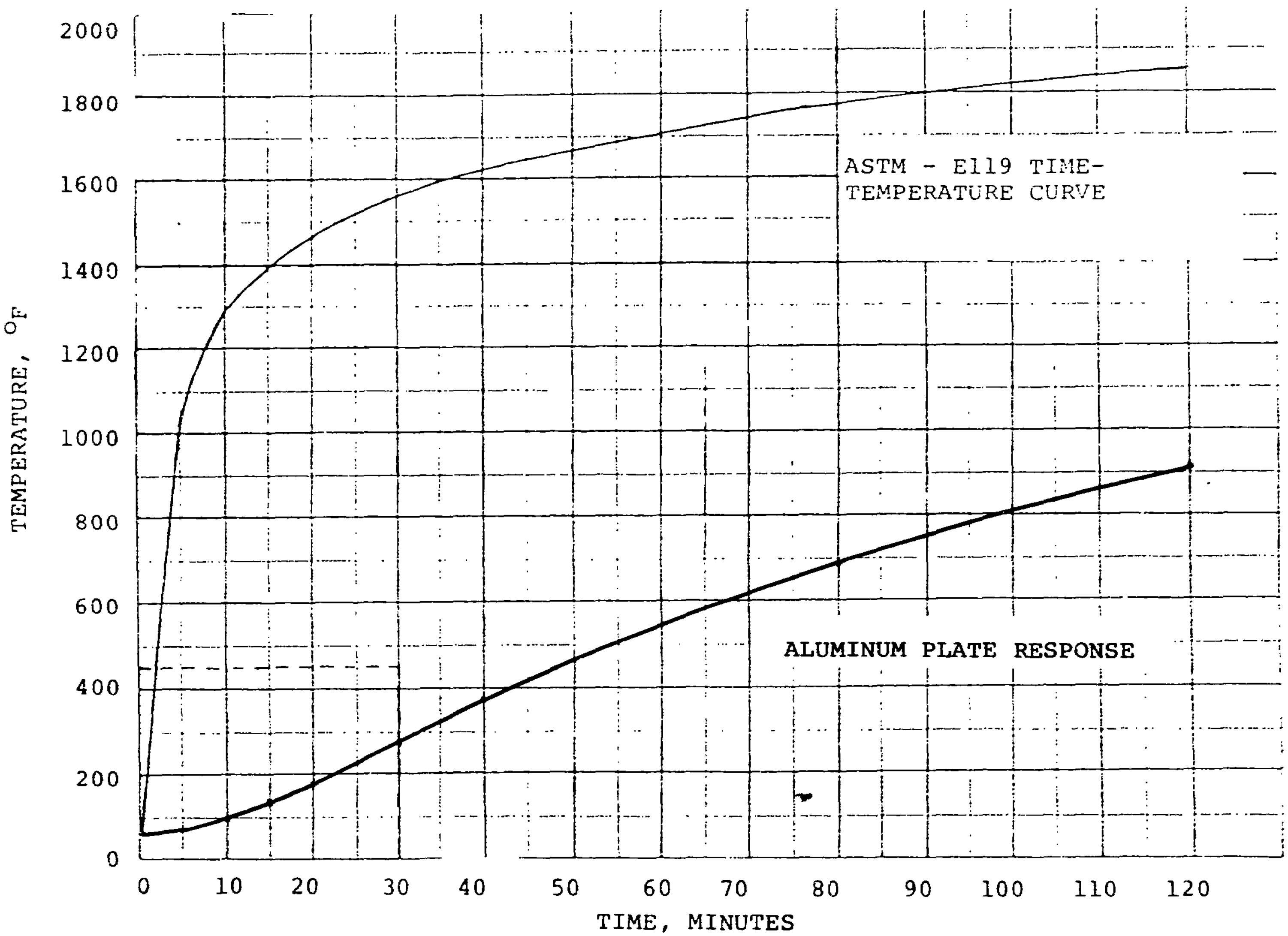
HEATING 5 EVALUATION - **MIN-K 2000 -- 1 inch, 20pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

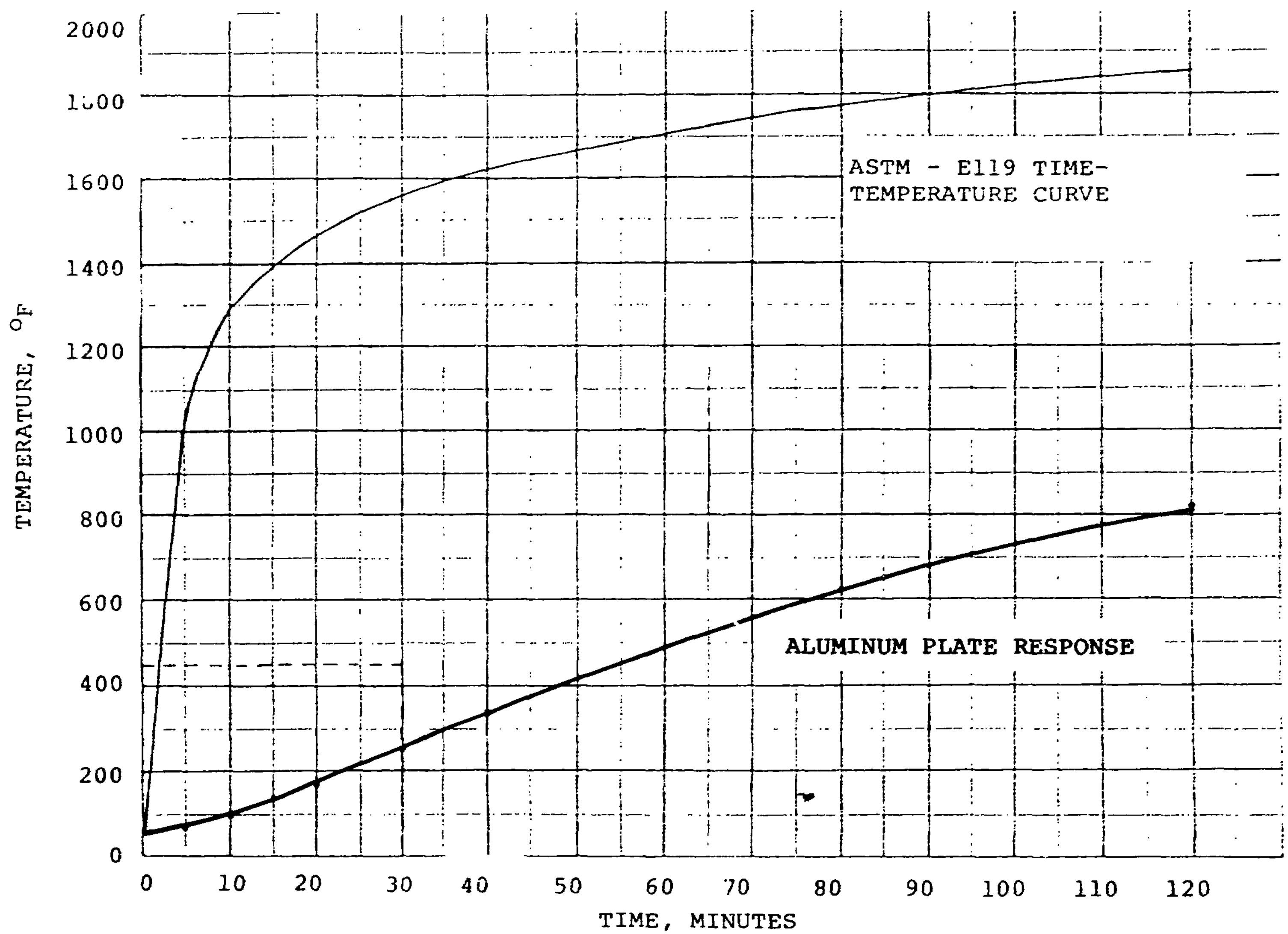
HEATING 5 EVALUATION - **MIN-K TE1400 -- 1/2 inch, 20pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

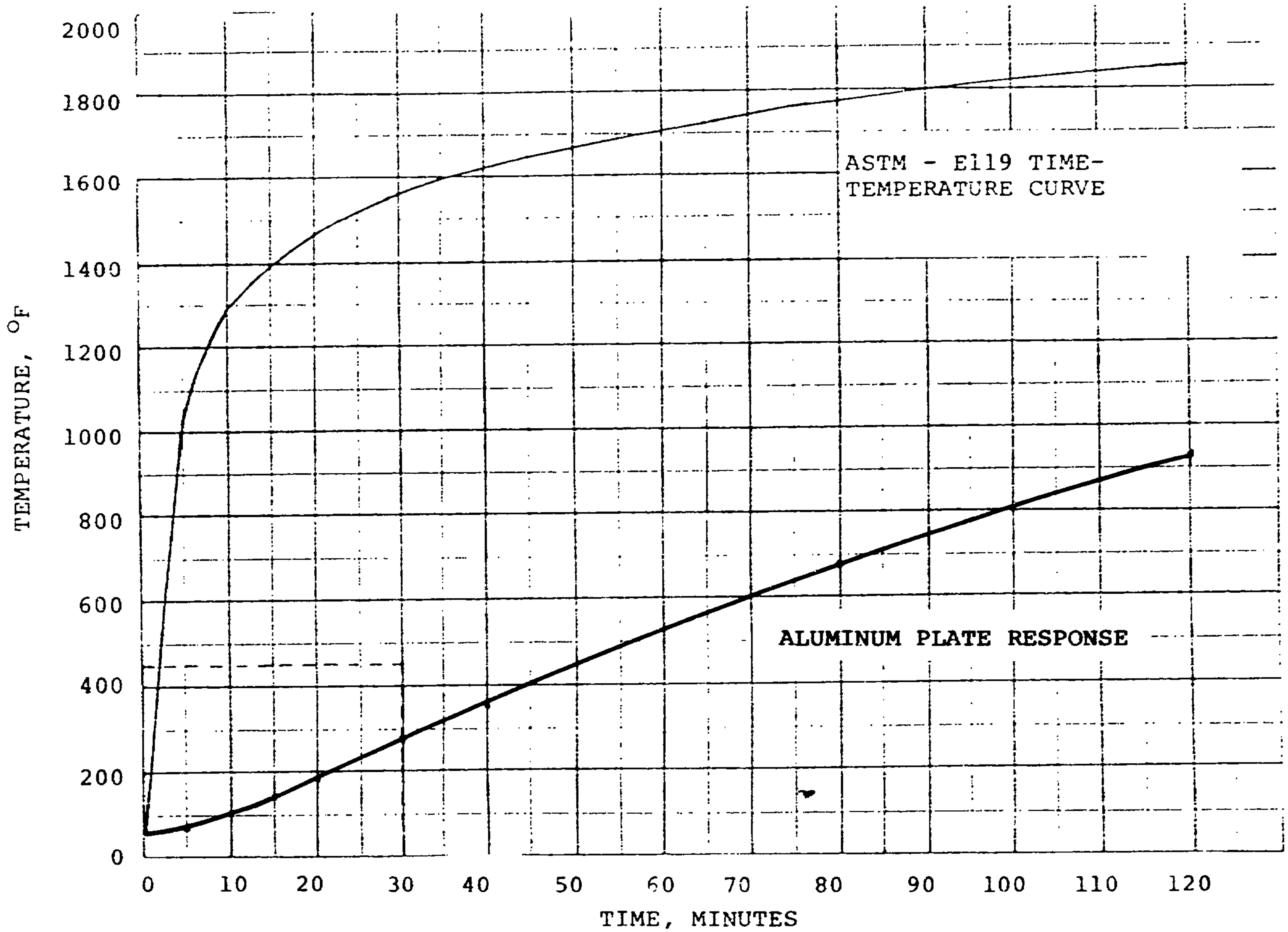
HEATING 5 EVALUATION - **MIN-K 1301 -- 3/8 inch, 20pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

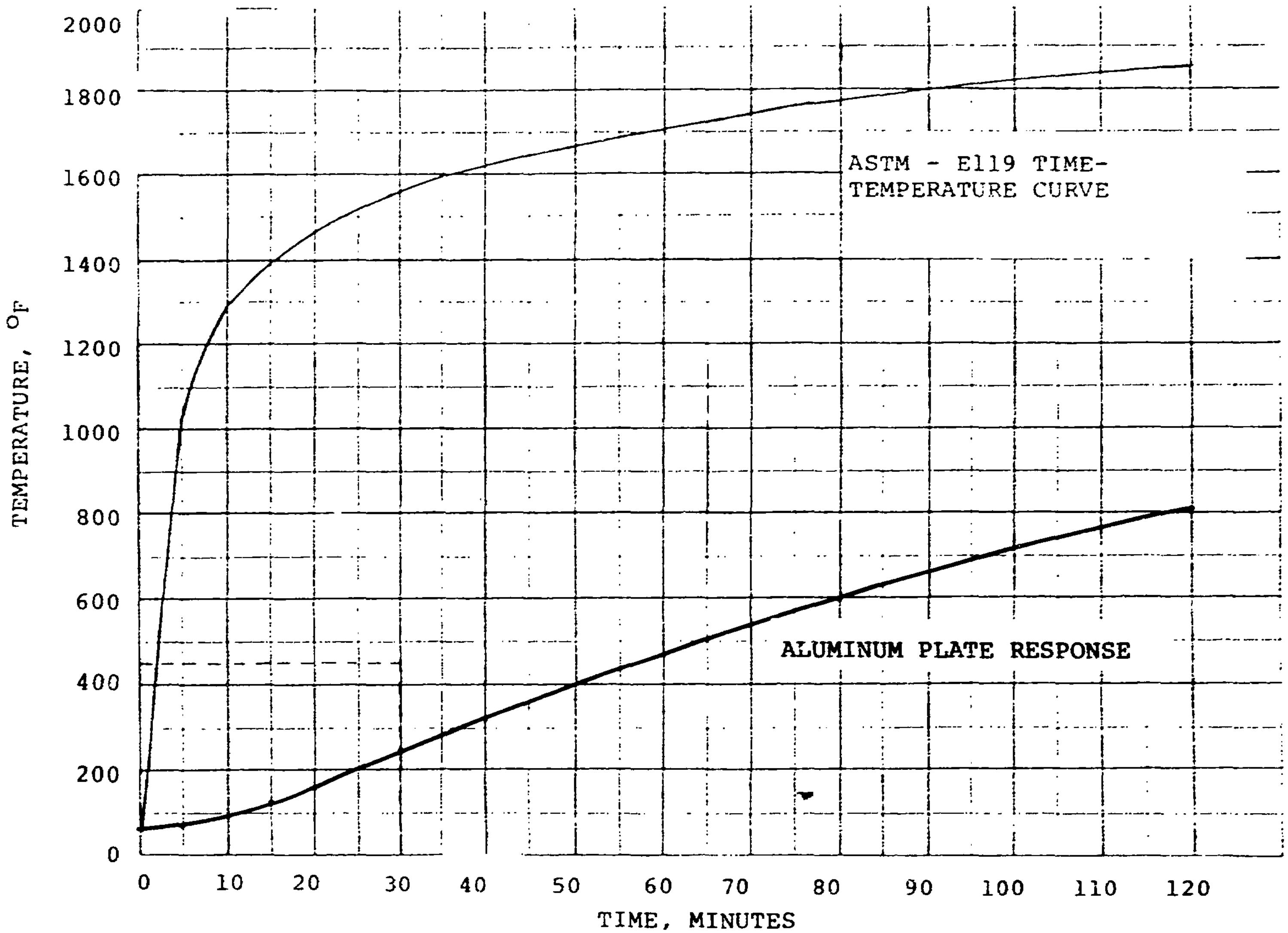
HEATING 5 EVALUATION - **MIN-K 2000 -- 3/8 inch, 20pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

HEATING 5 EVALUATION - **MIN-K TE1400 -- 3/8 inch, 20pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413

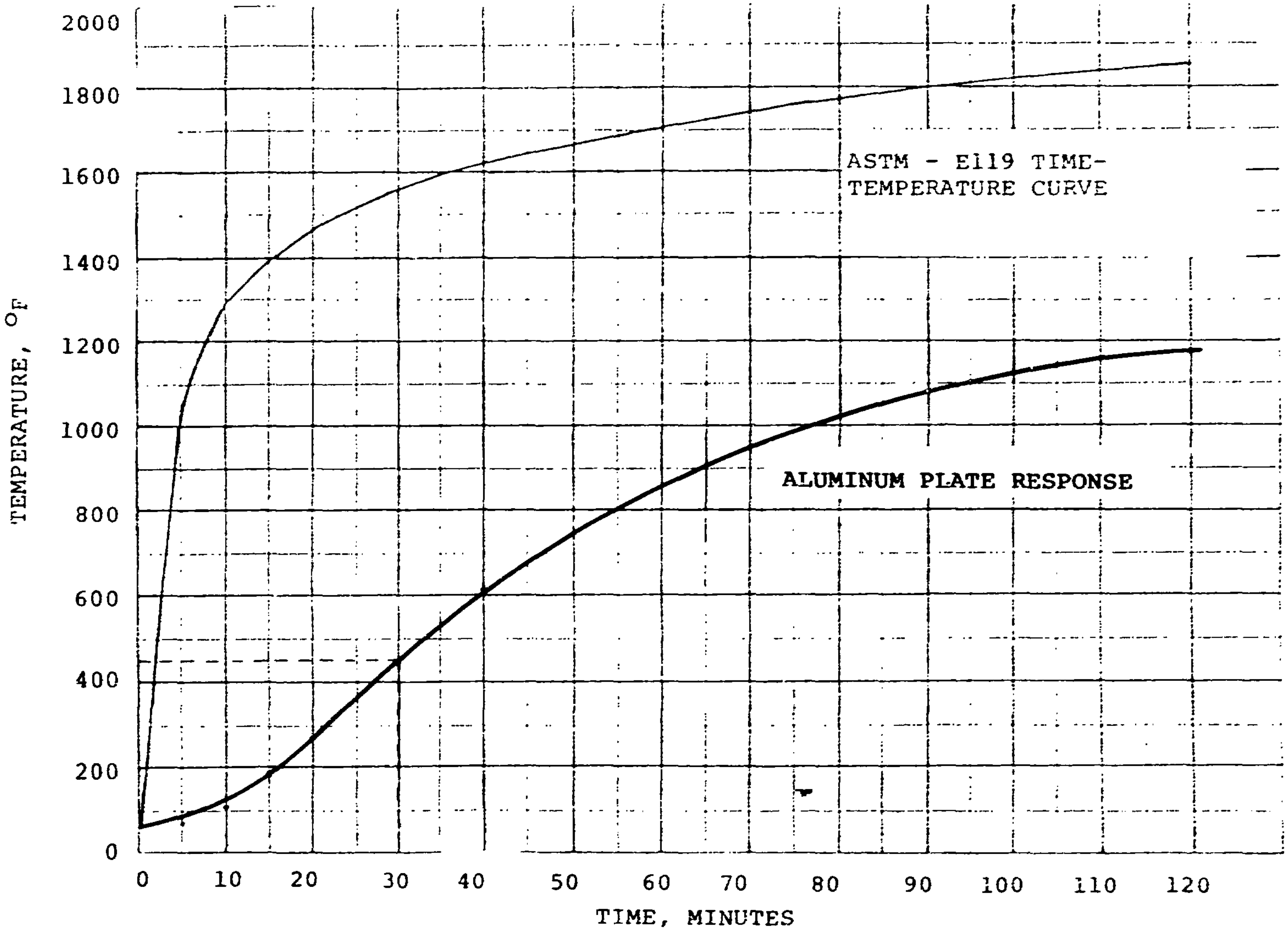


APPENDIX C

GRAPH OF RESULTS

HEATING 5 EVALUATION - **CERAFORM 126 -- 1/4 inch, 18.5pcf**
PLUS - Q-FIBER -- 1/2 inch, 6pcf
NAVY CONTRACT N00173-80-C-0413

DOUBLE INSULATED CONFIGURATION

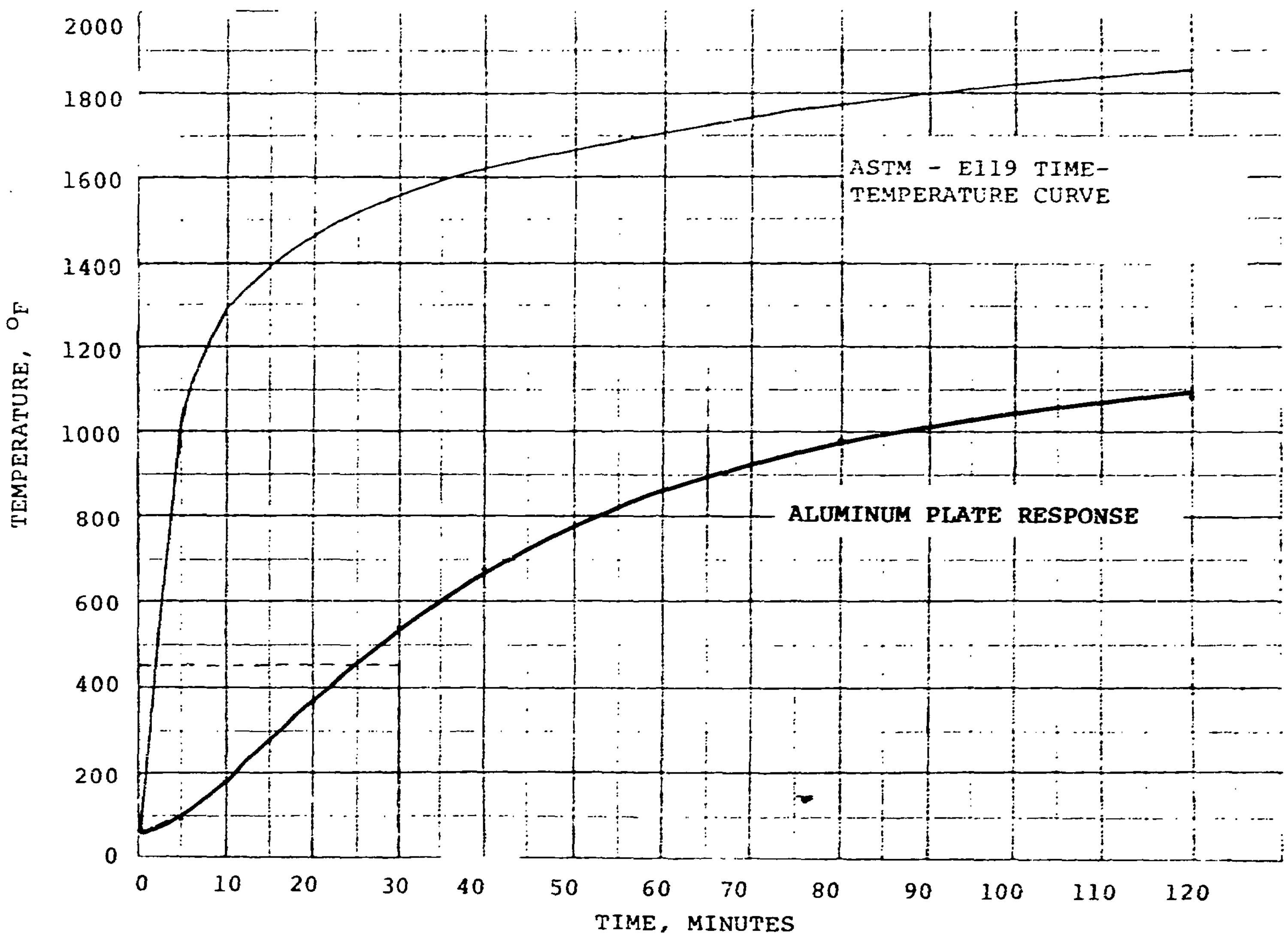


APPENDIX C

GRAPH OF RESULTS

HEATING 5 EVALUATION - **FLEXIBLE MIN-K -- 1/4 inch, 8pcf Core**
PLUS - CERAFELT -- 1/4 inch, 4pcf
NAVY CONTRACT N00173-80-C-0413

DOUBLE INSULATED CONFIGURATION

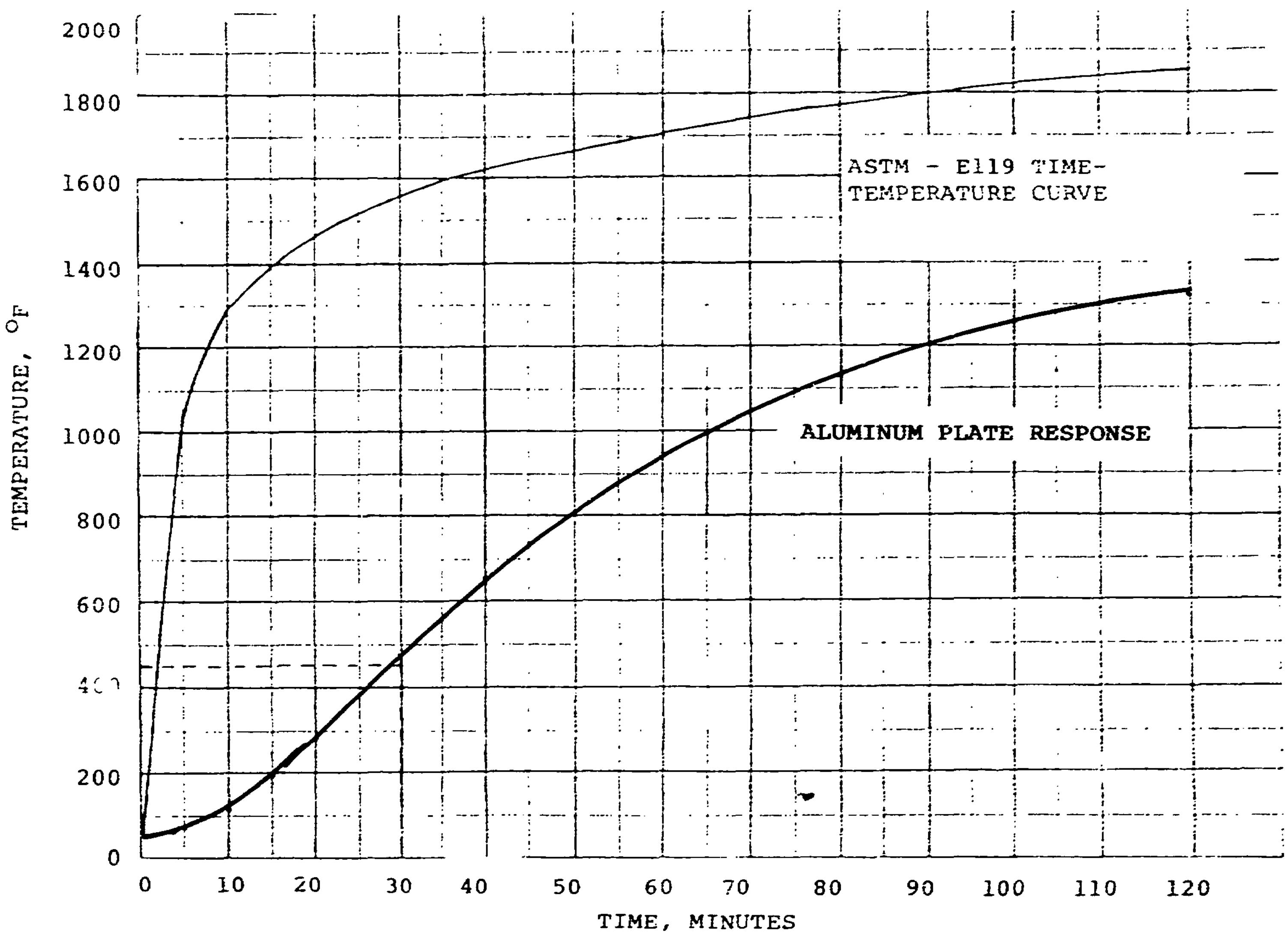


APPENDIX C

GRAPH OF RESULTS

HEATING 5 EVALUATION - **CERAFORM 126 -- 1/4 inch, 18.5pcf**
PLUS - LO CON -- 1/2 inch, 6pcf
NAVY CONTRACT N00173-80-C-0413

DOUBLE INSULATED CONFIGURATION

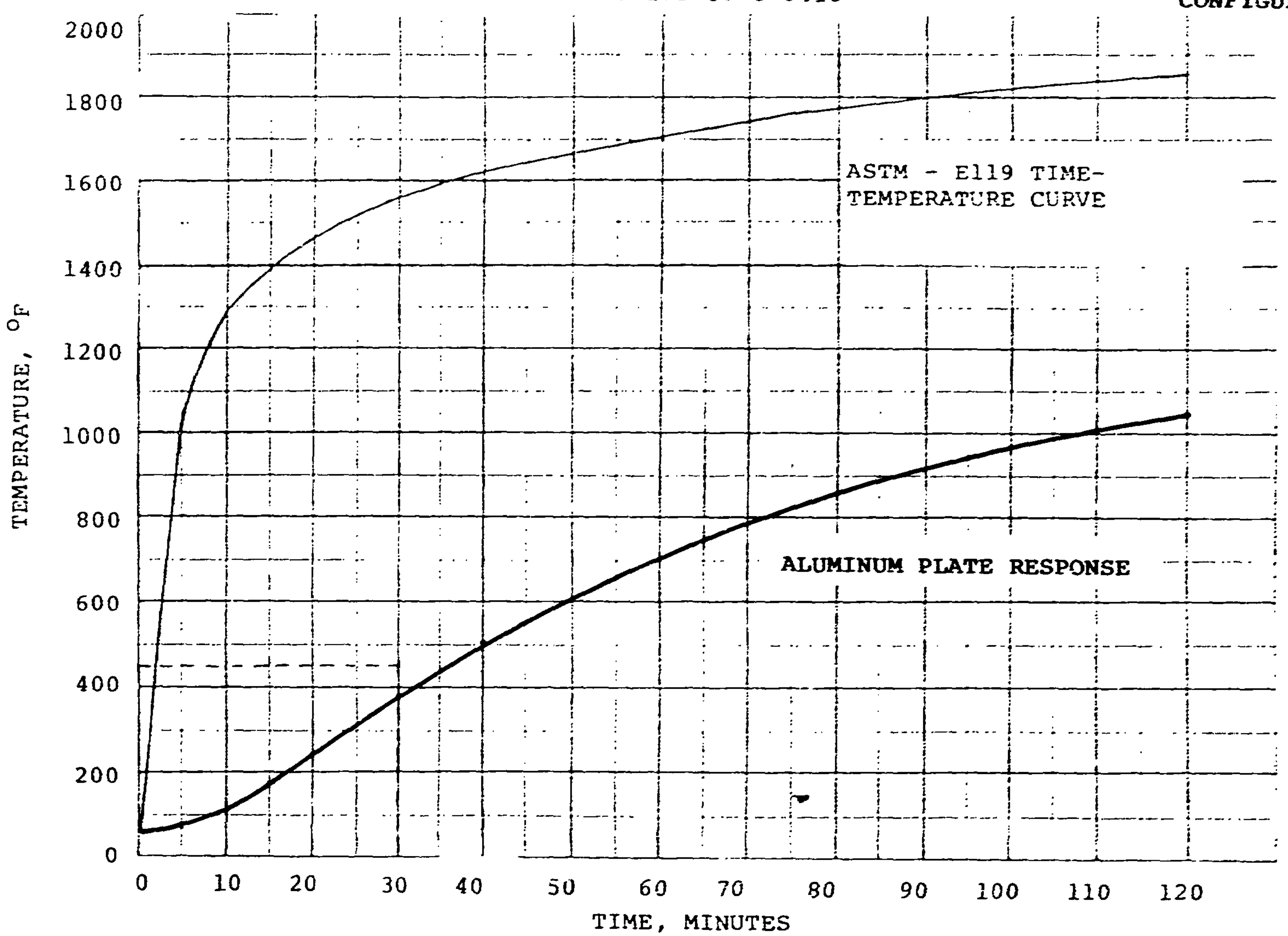


APPENDIX C

GRAPH OF RESULTS

HEATING 5 EVALUATION - **MIN-K TE1400 -- 1/4 inch, 20pcf**
PLUS - MICROLITE B -- 1/4 inch, 4.5pcf
NAVY CONTRACT N00173-80-C-0413

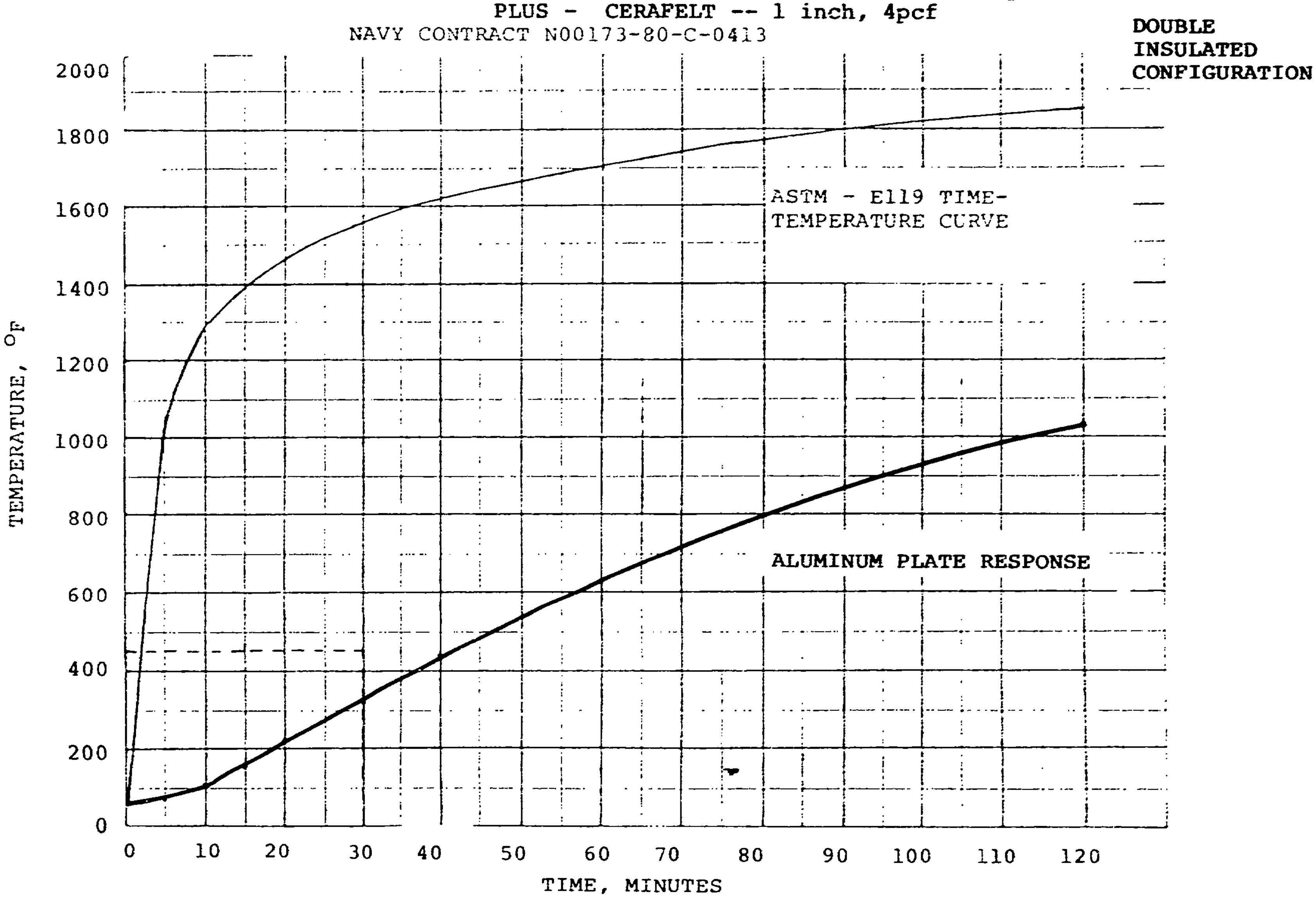
DOUBLE INSULATED CONFIGURATION



APPENDIX C

GRAPH OF RESULTS

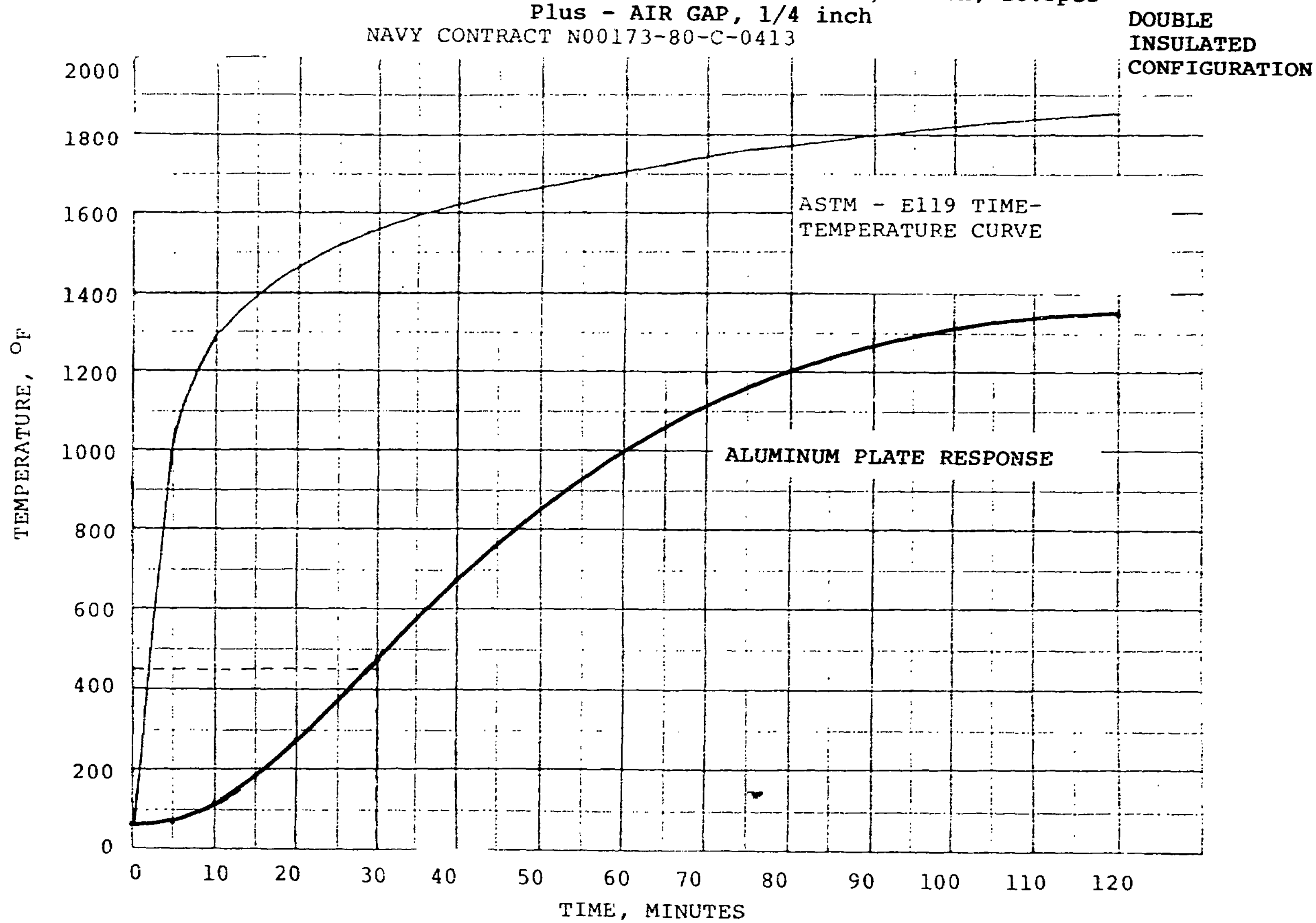
HEATING 5 EVALUATION - **FLEXIBLE MIN-K -- 1/4 inch, 8pcf Core**
PLUS - CERAFELT -- 1 inch, 4pcf
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

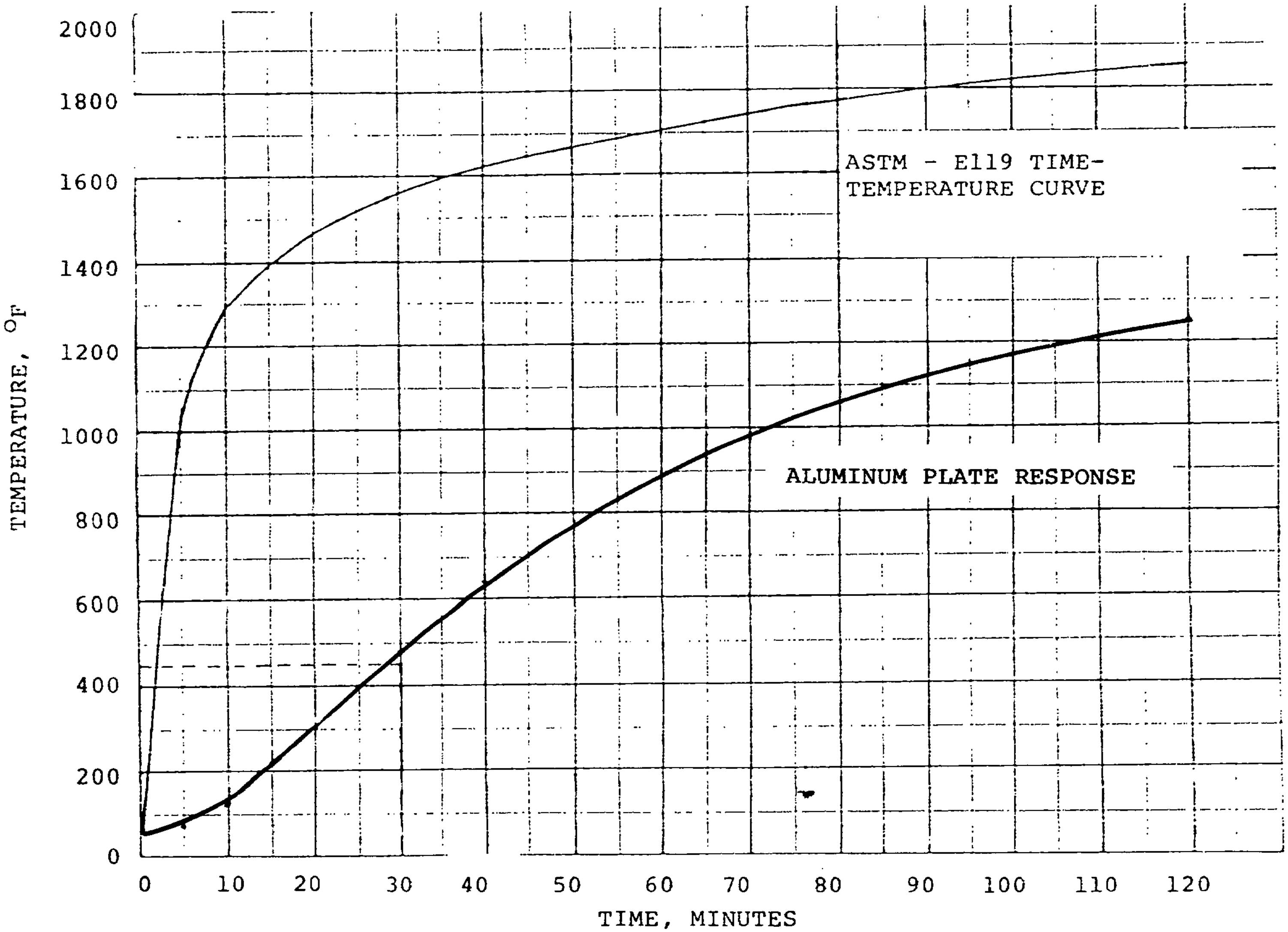
HEATING 5 EVALUATION - **CERAFORM 126 -- 1/2 inch, 18.5pcf**
Plus - AIR GAP, 1/4 inch
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

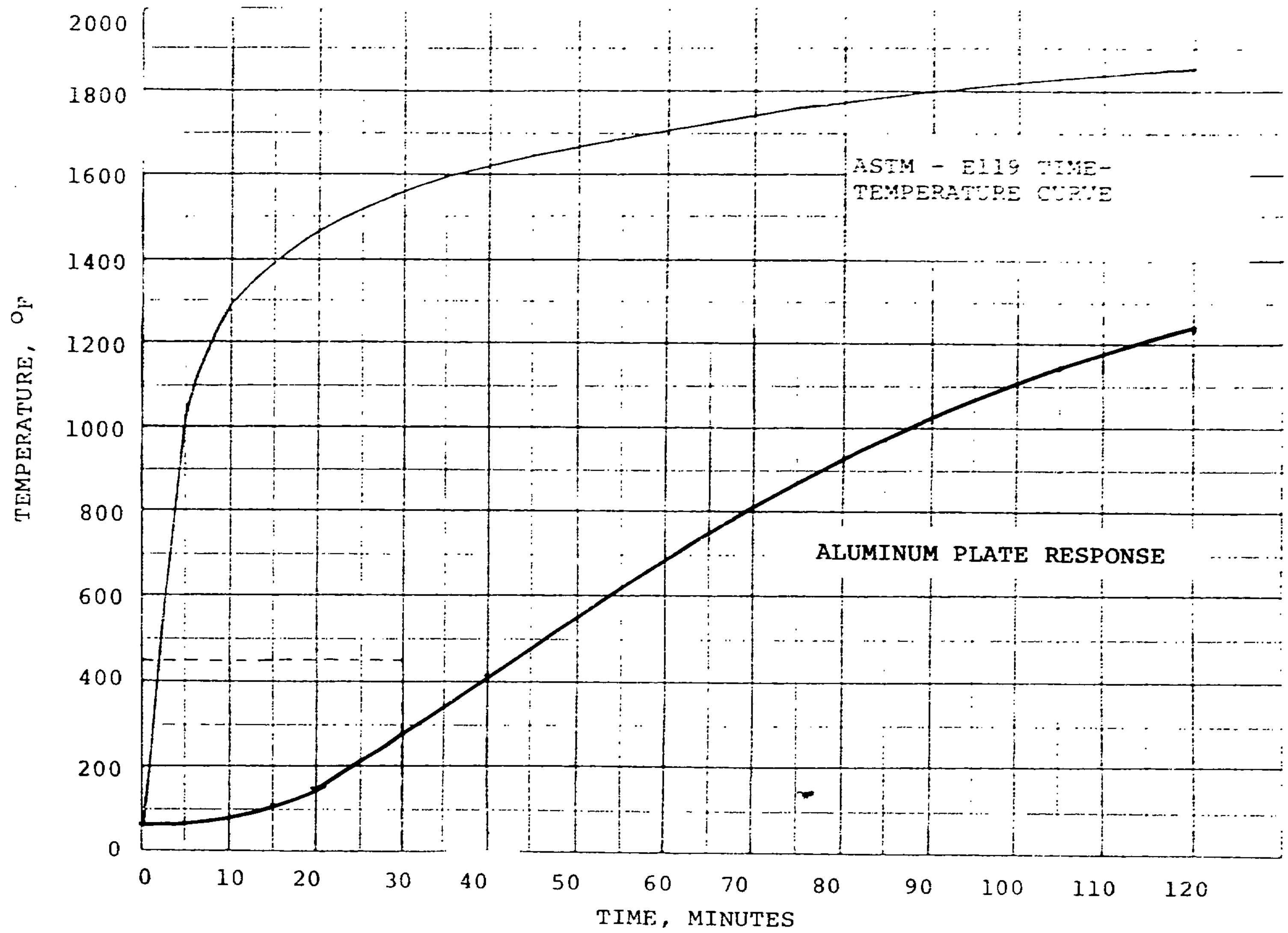
HEATING 5 EVALUATION - THERMOFLEX II -- 3/4 inch, 12pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

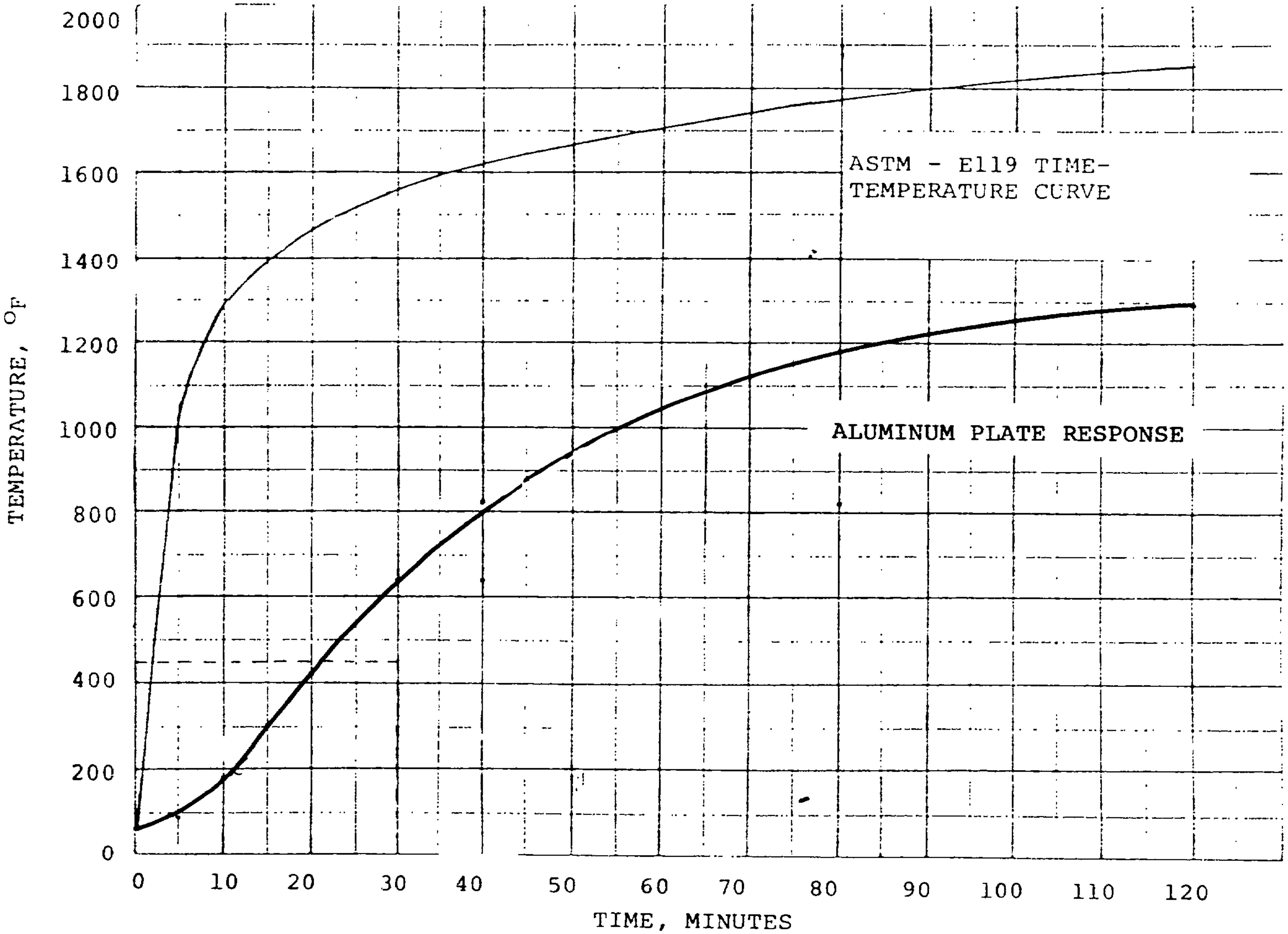
HEATING 5 EVALUATION - **CERAFORM 103 -- 1 inch, 13.5pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

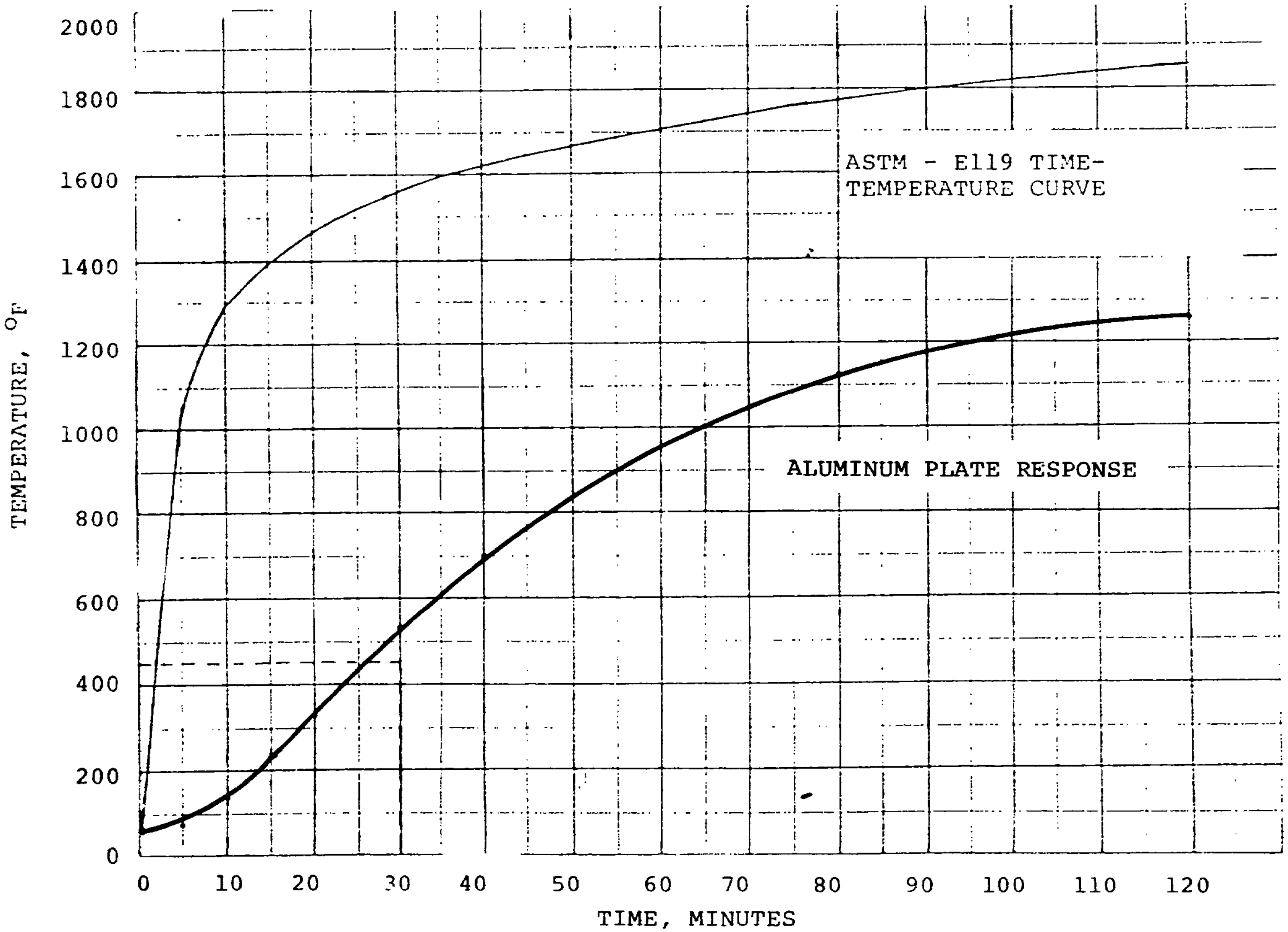
HEATING 5 EVALUATION - THERMOFLEX II -- 1/2 inch, 12pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

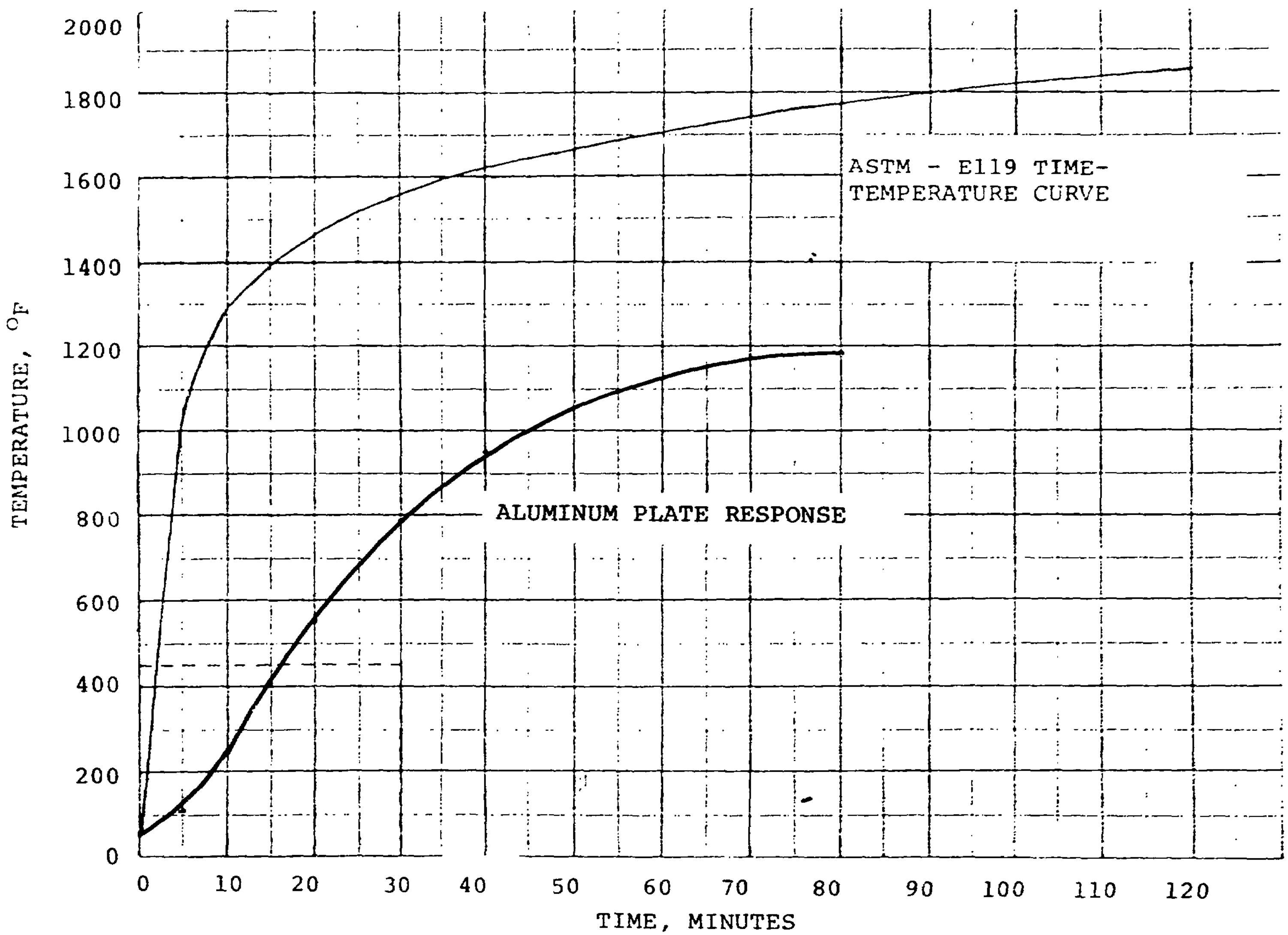
HEATING 5 EVALUATION - KAOWOOL -- 1 inch, 8pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

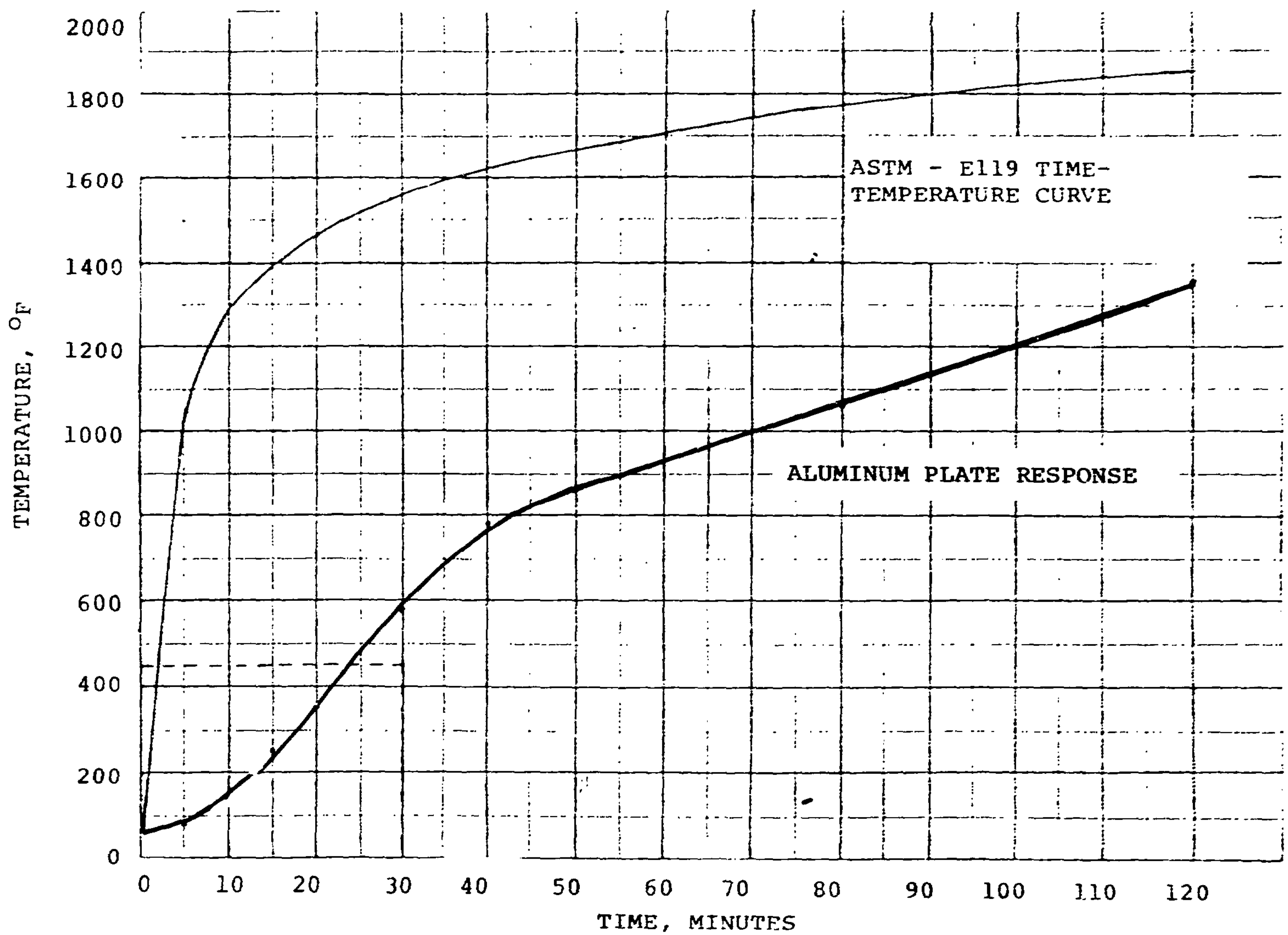
HEATING 5 EVALUATION - Q-FIBER -- 1/2 inch, 6pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

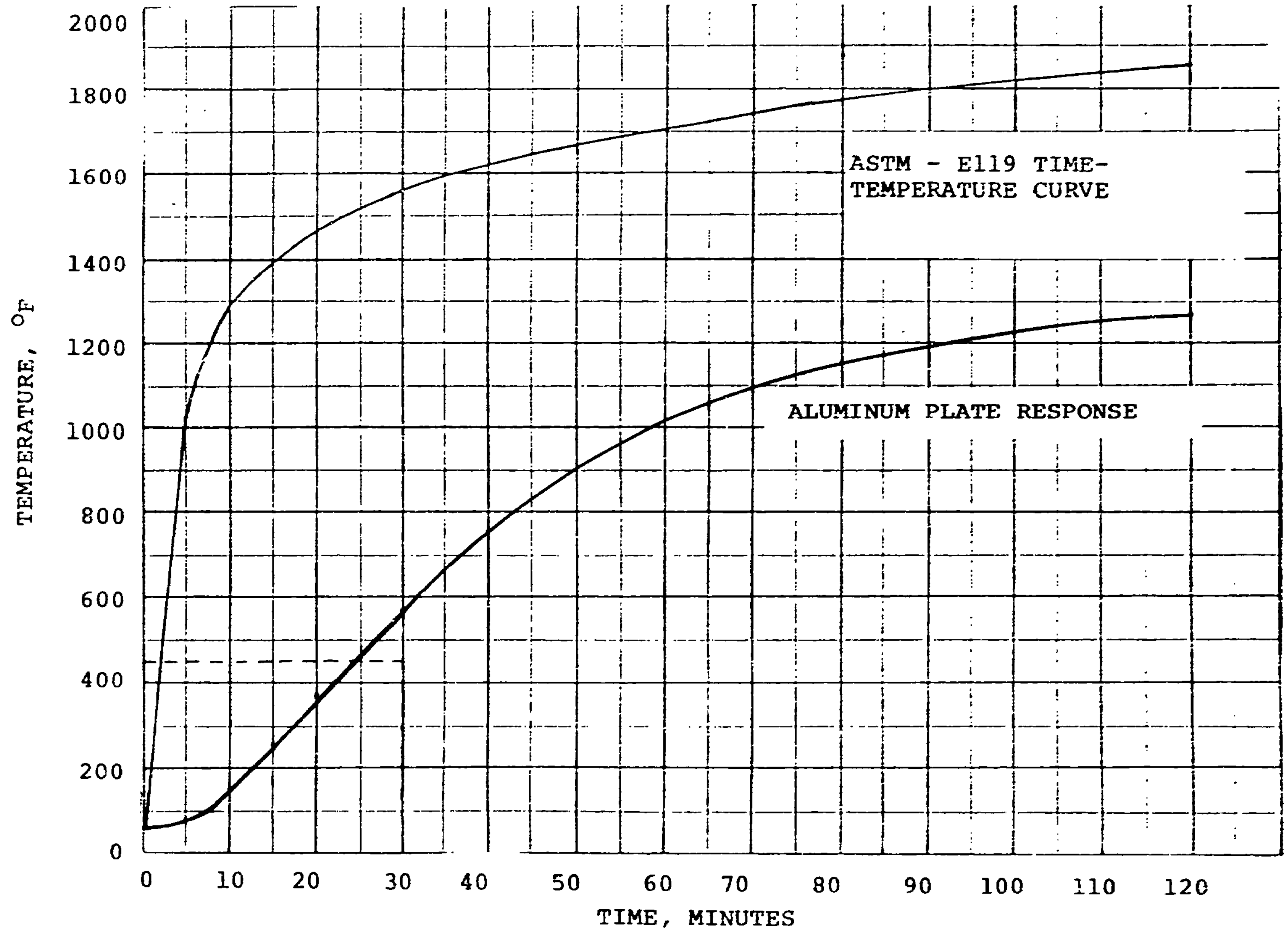
HEATING 5 EVALUATION - CERAFORM 103 -- 1/4 inch, 13.5pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

HEATING 5 EVALUATION - LO CON -- 1 inch, 6pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413

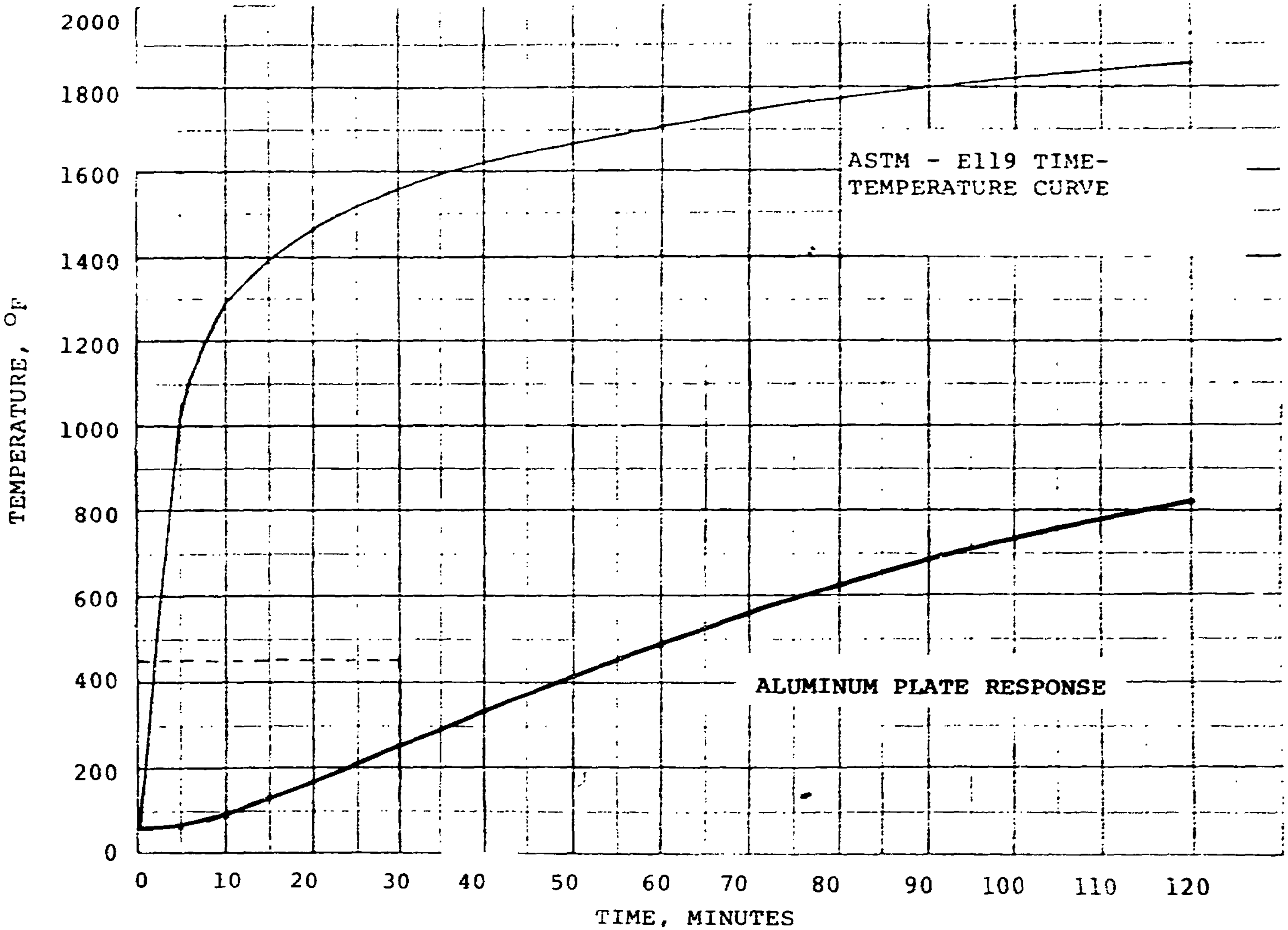


APPENDIX C

GRAPH OF RESULTS

HEATING 5 EVALUATION - **CERAFELT -- 1/2 inch, 4pcf**
Plus - FOAM -- 1 inch, 3pcf
NAVY CONTRACT N00173-80-C-0413

DOUBLE INSULATED CONFIGURATION

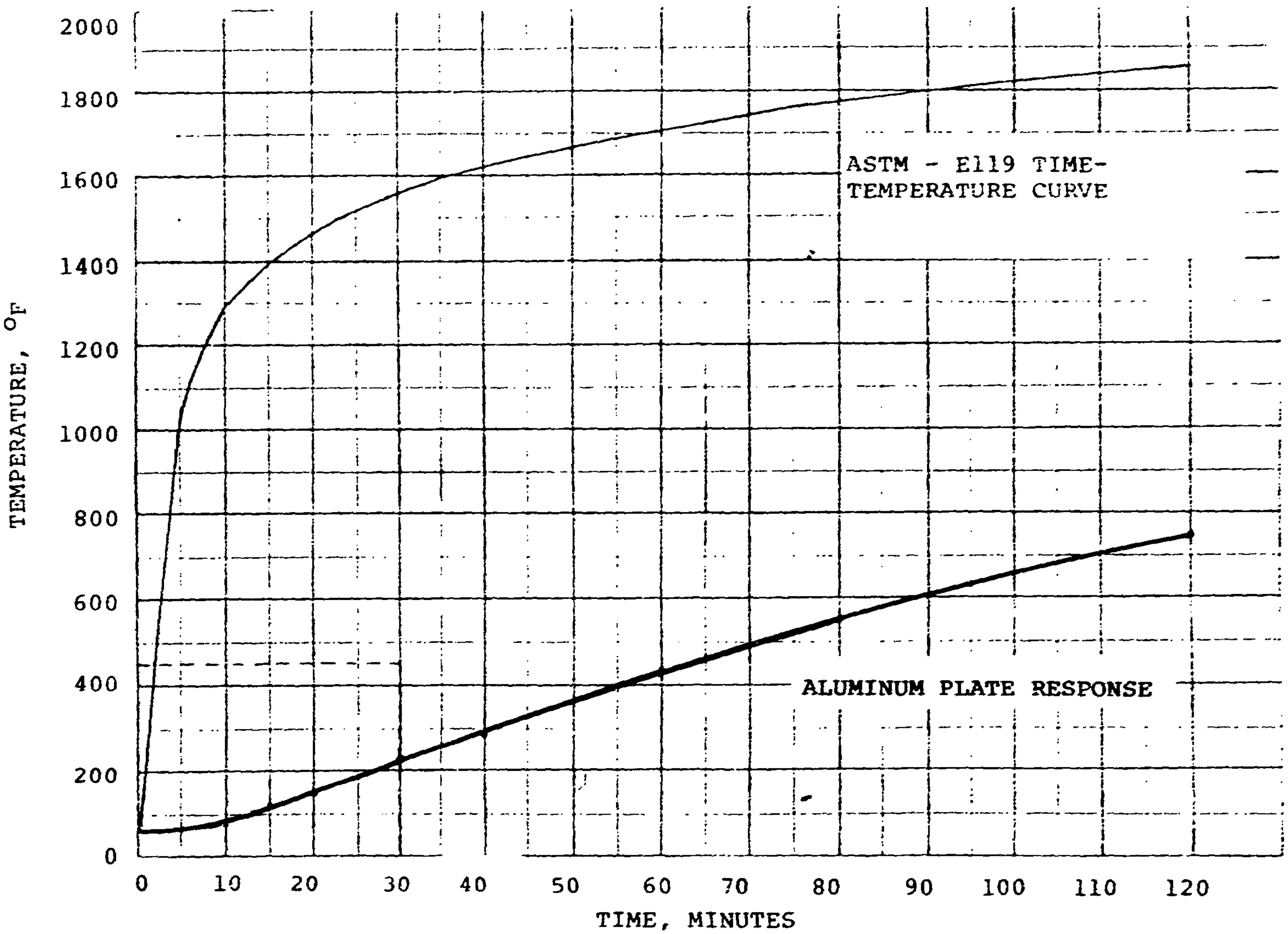


APPENDIX C

GRAPH OF RESULTS

HEATING 5 EVALUATION - Q-FIBER -- 1/2 inch, 6pcf
Plus - FOAM -- 1 inch, 3pcf
NAVY CONTRACT N00173-80-C-0413

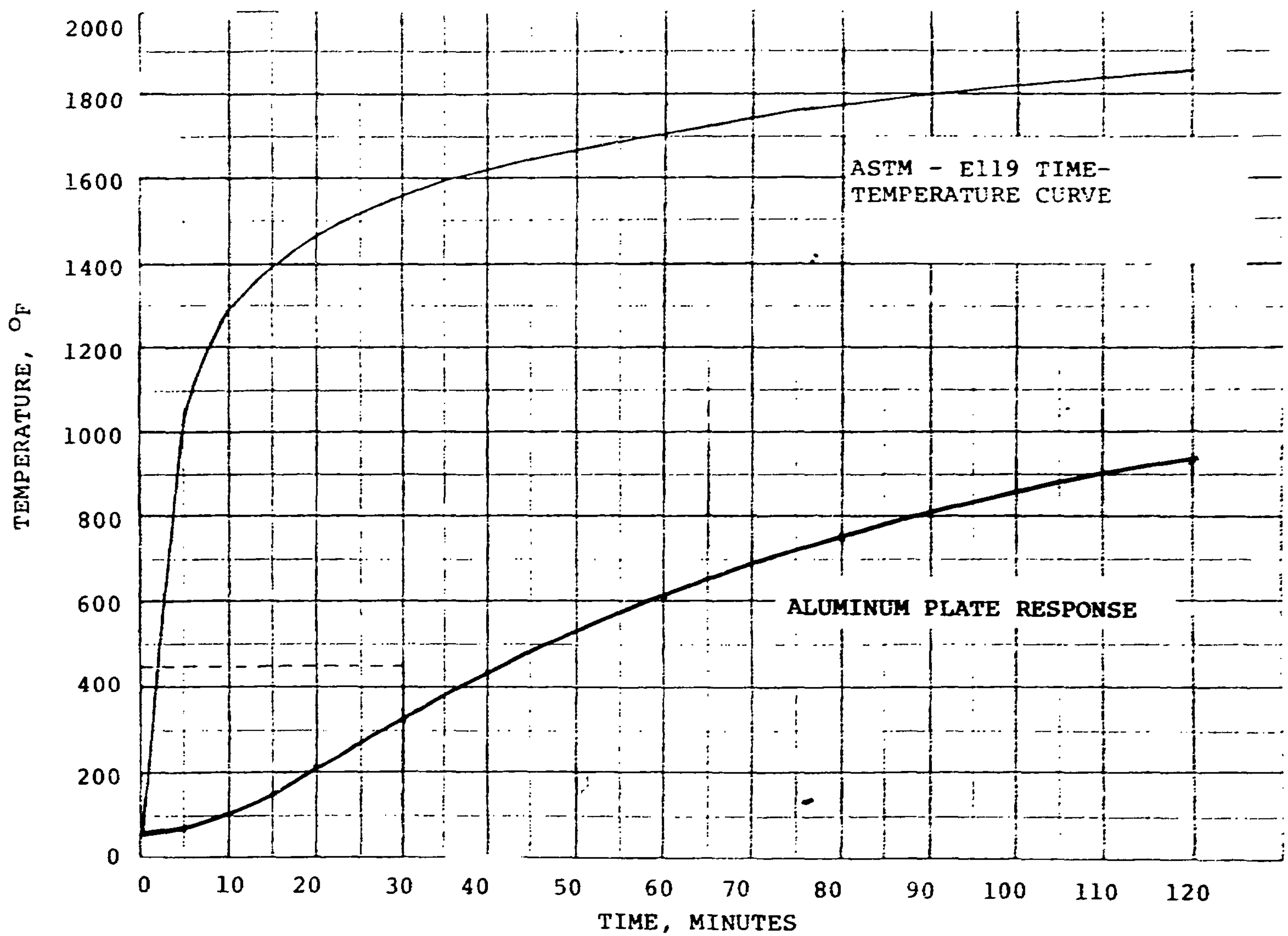
DOUBLE
INSULATED
CONFIGURATION



APPENDIX C

GRAPH OF RESULTS

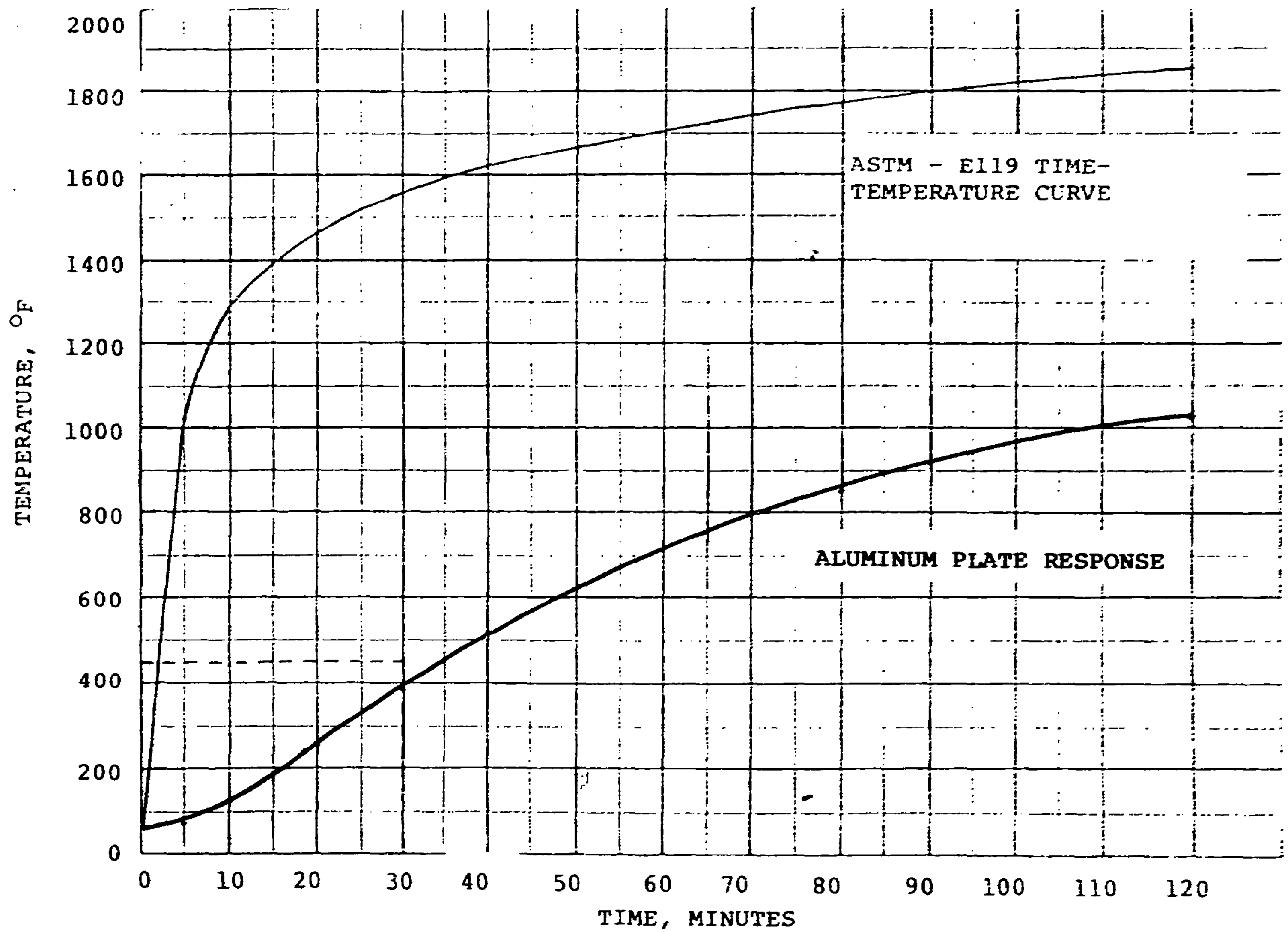
HEATING 5 EVALUATION - Q-FIBER -- 1/2 inch, 6pcf Plus FOAM -- 1/2 inch, 3pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

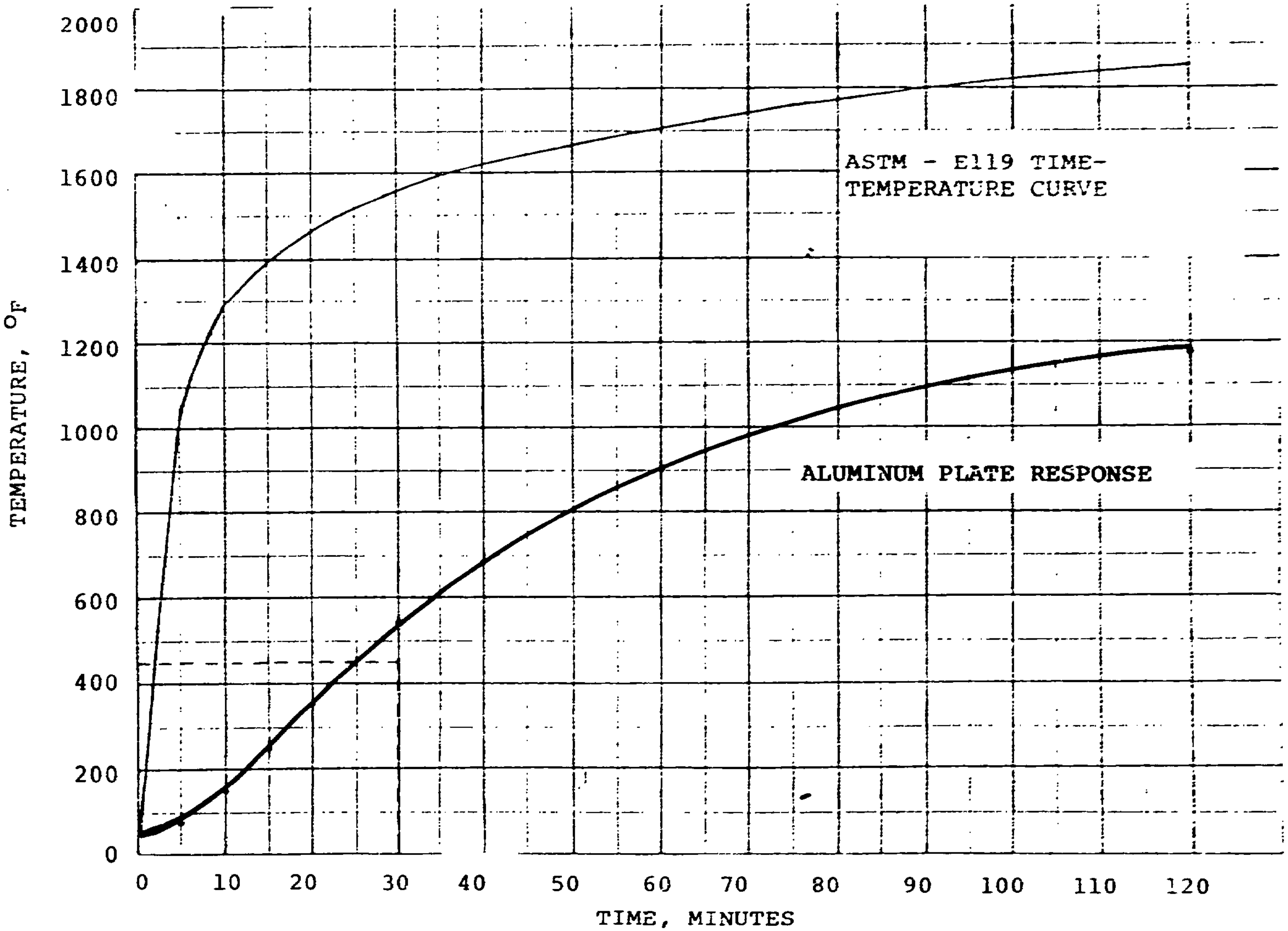
HEATING 5 EVALUATION - CERAFELT -- 1/2 inch, 4pcf <u>PLUS</u> FOAM -- 1/2 inch, 3pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

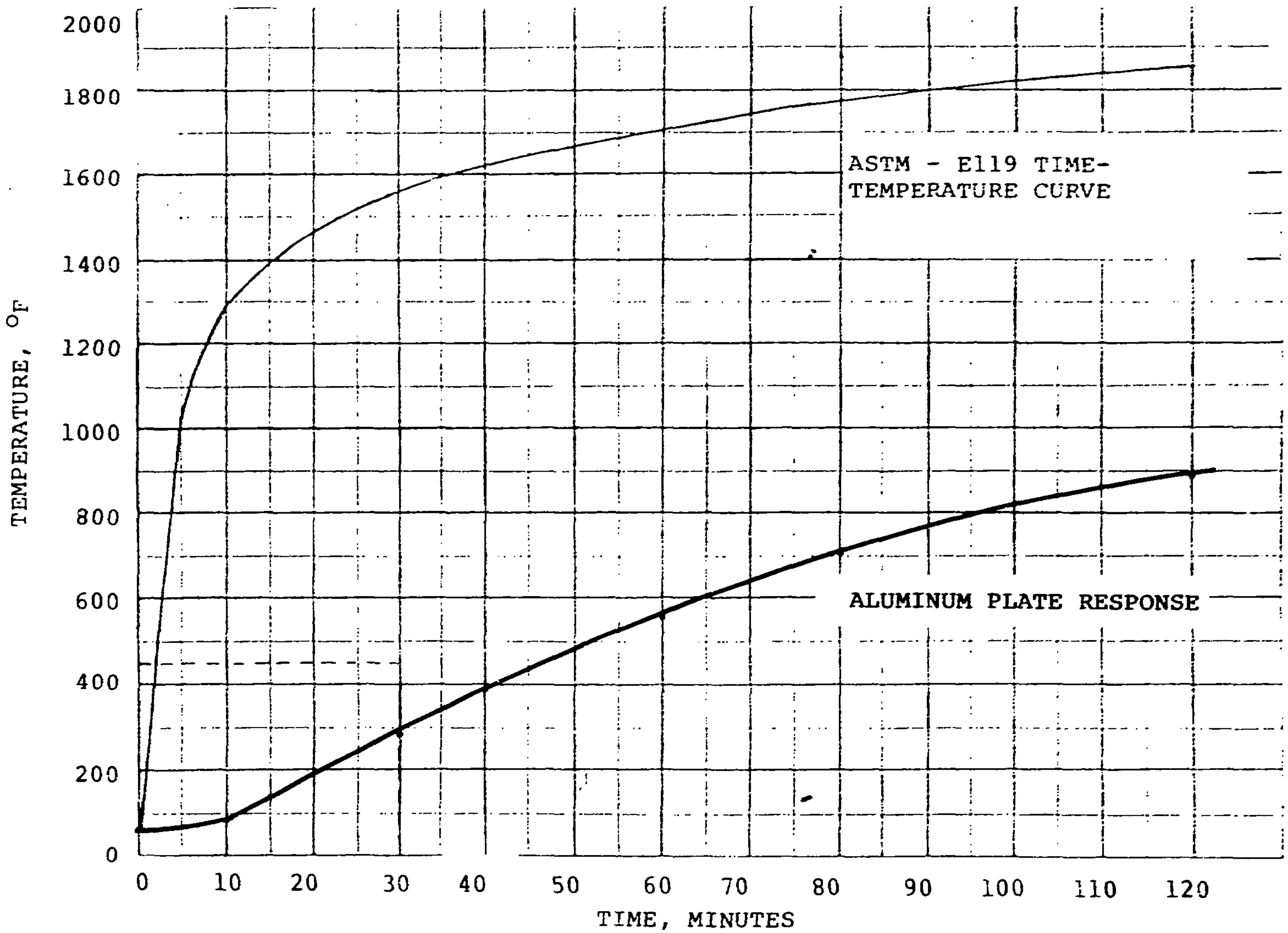
HEATING 5 EVALUATION - **CERAFELT -- 1/2 inch, 4pcf PLUS FOAM -- 1/4 inch, 3pcf**
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

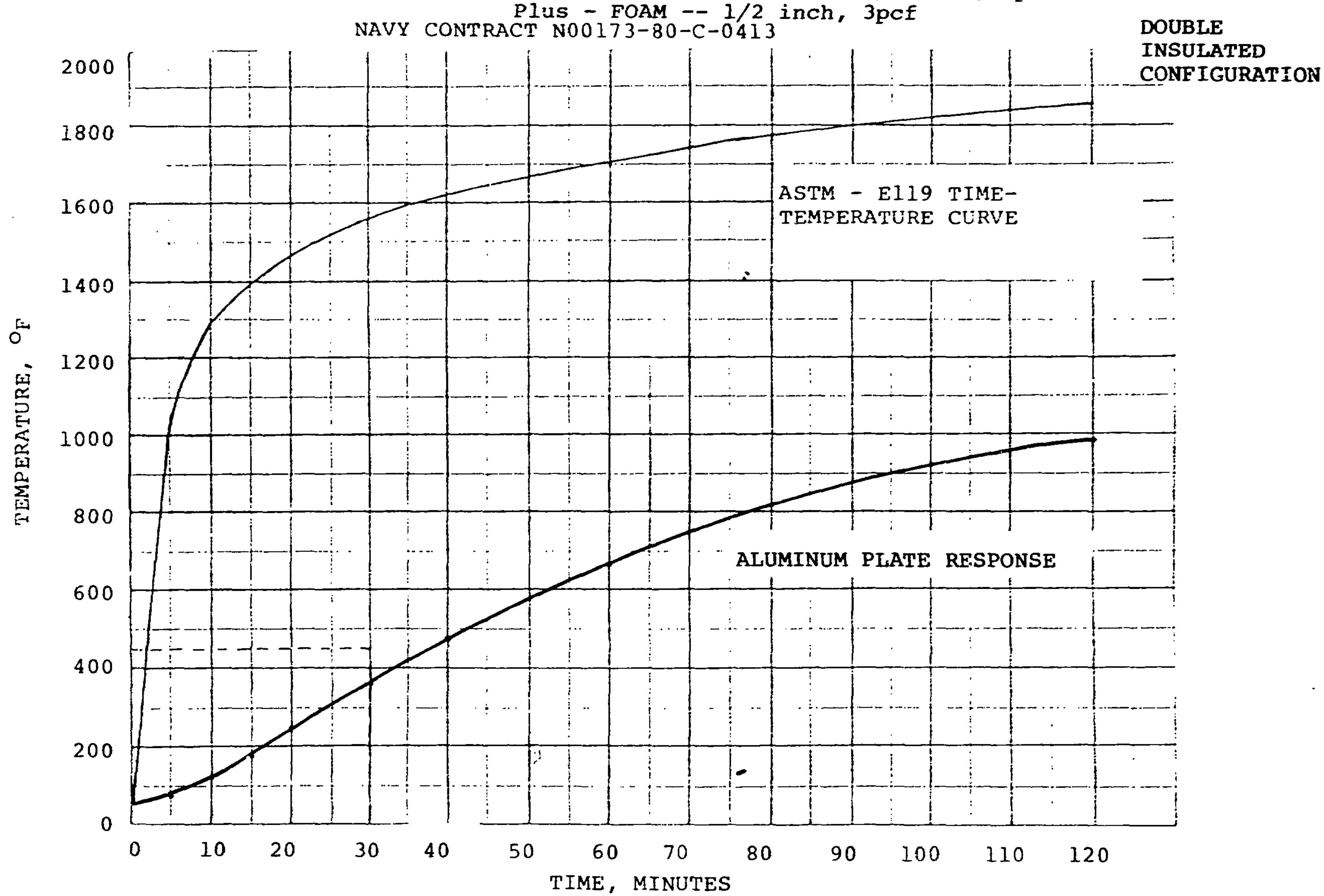
HEATING 5 EVALUATION - **MIN-K TE1400 -- 1/4 inch, 20pcf PLUS FOAM -- 1/2 inch**
DOUBLE INSULATED CONFIGURATION **3pcf**
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

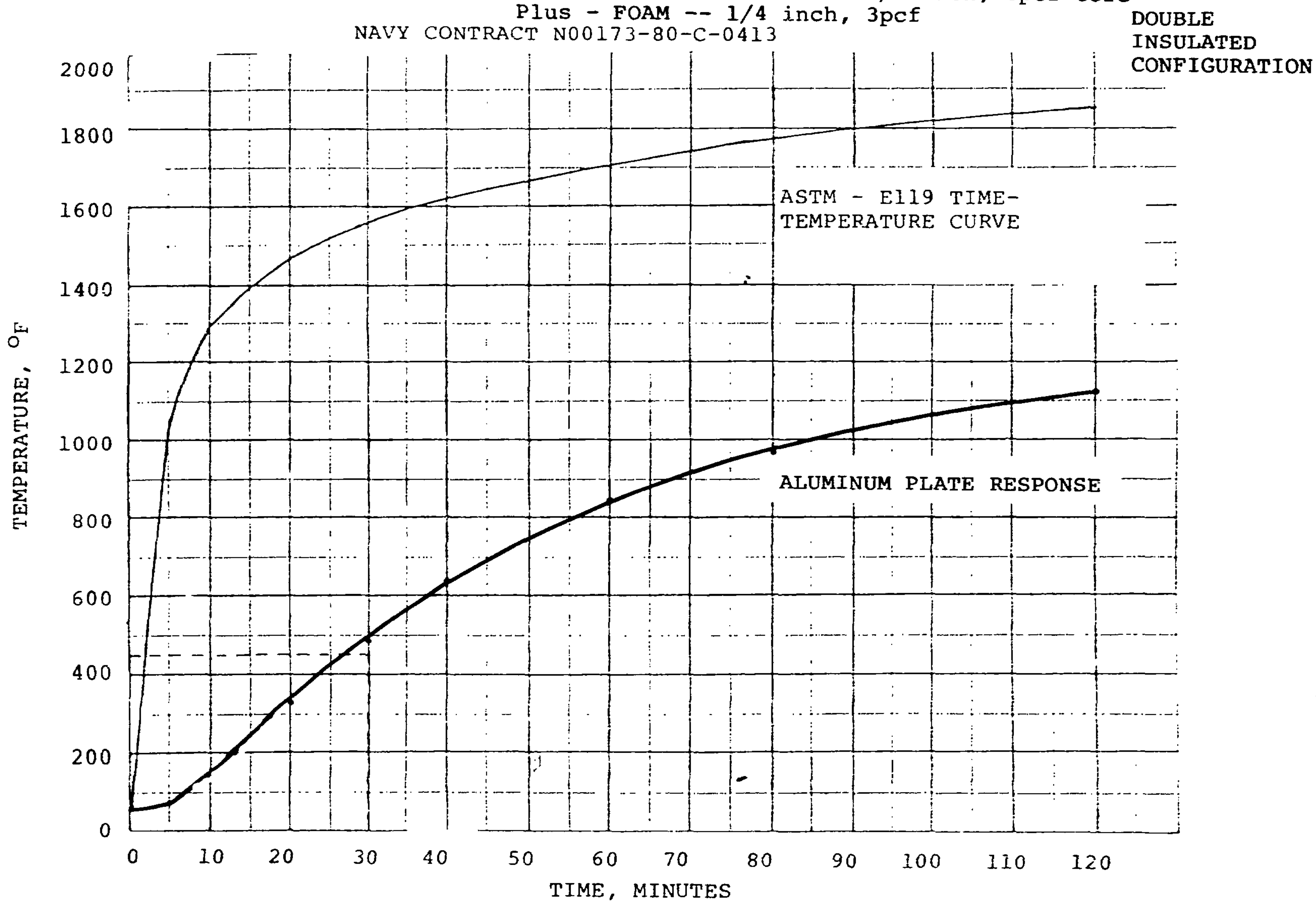
HEATING 5 EVALUATION - FLEXIBLE MIN-K -- 1/4 inch, 8pcf Core
Plus - FOAM -- 1/2 inch, 3pcf
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

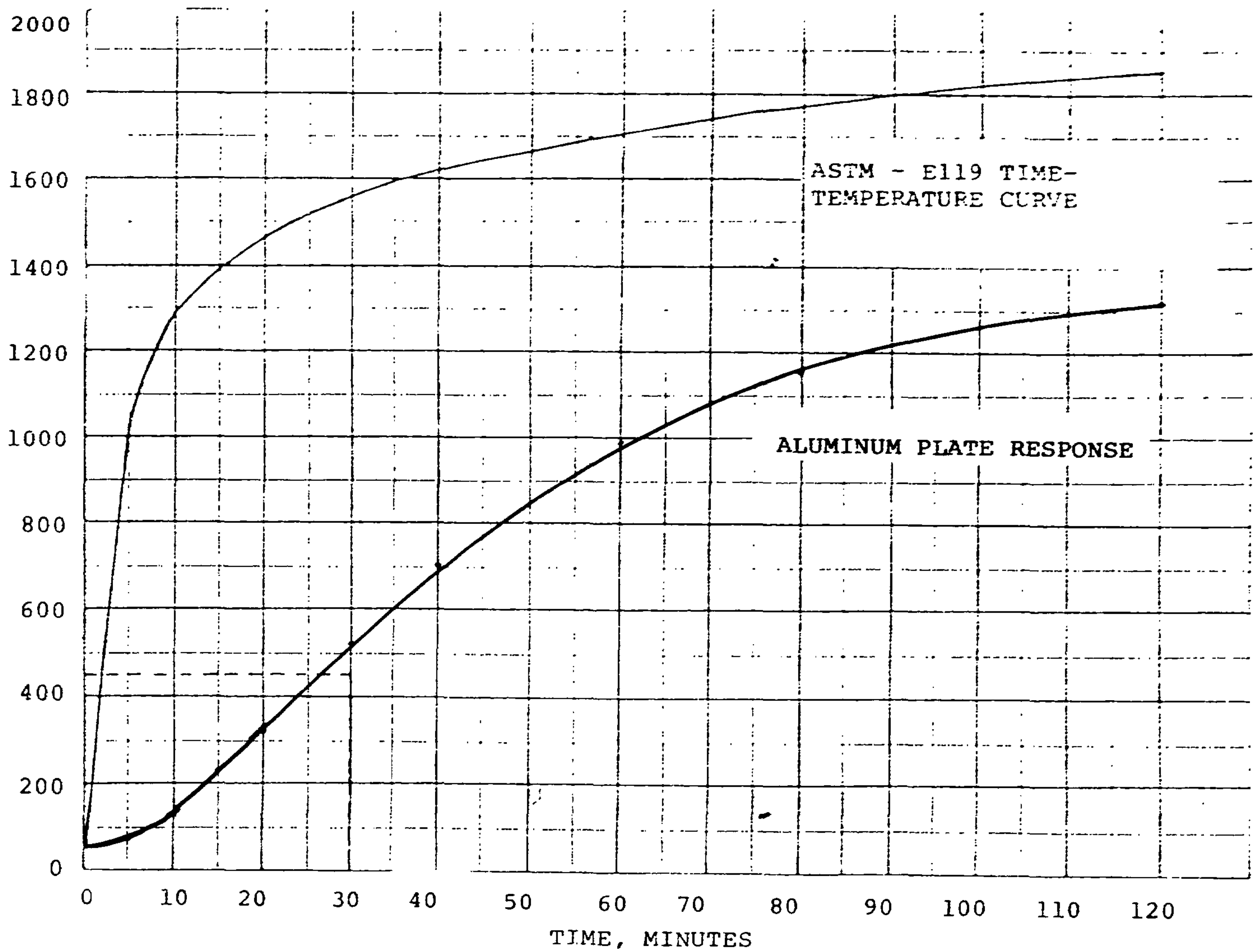
HEATING 5 EVALUATION - **FLEXIBLE MIN-K -- 1/4 inch, 8pcf Core**
Plus - FOAM -- 1/4 inch, 3pcf
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

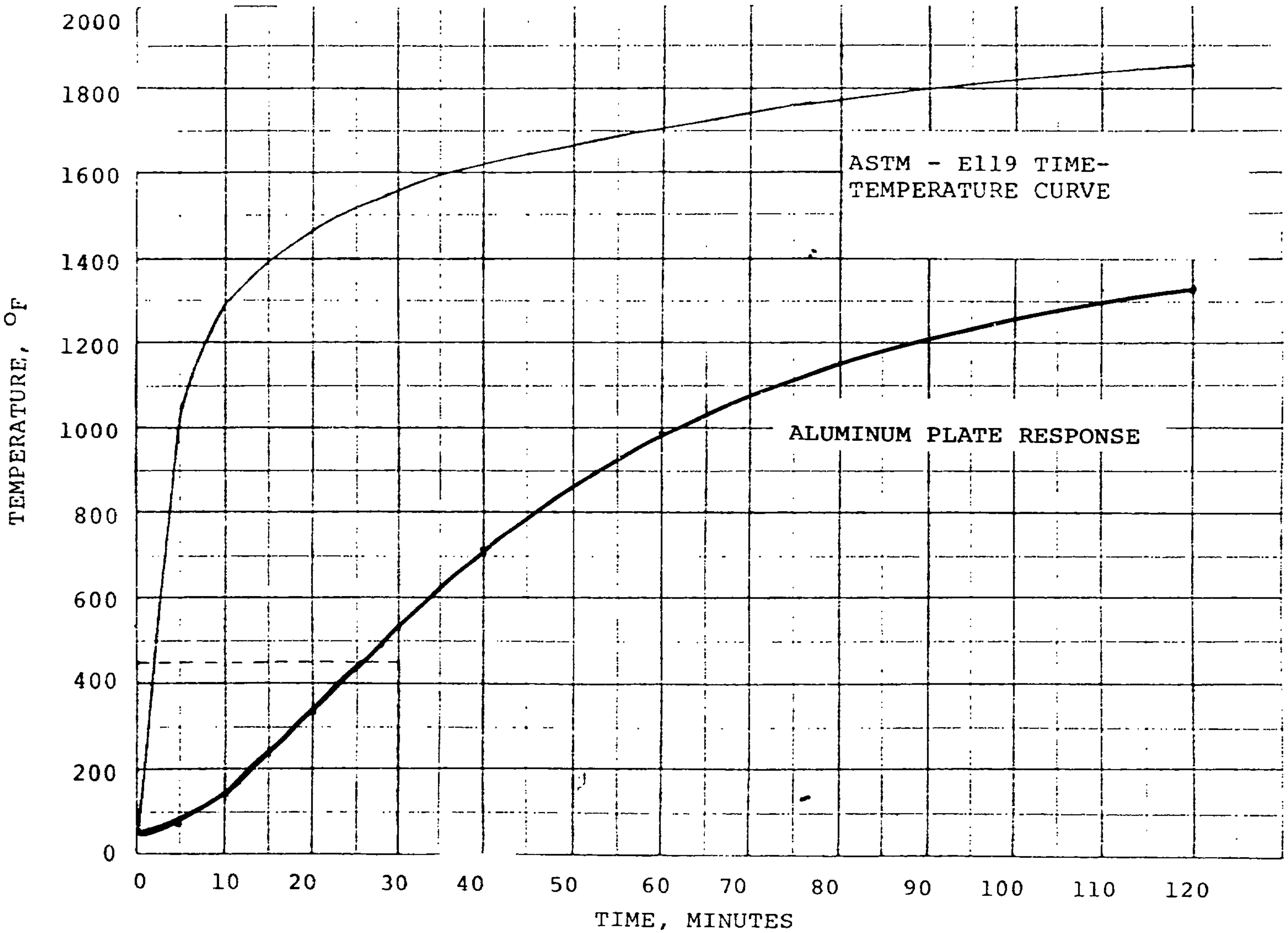
HEATING 5 EVALUATION - CERAFELT -- 1 inch, 4pcf PLUS Aluminum Skin - 0.1 inch, 168.5pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

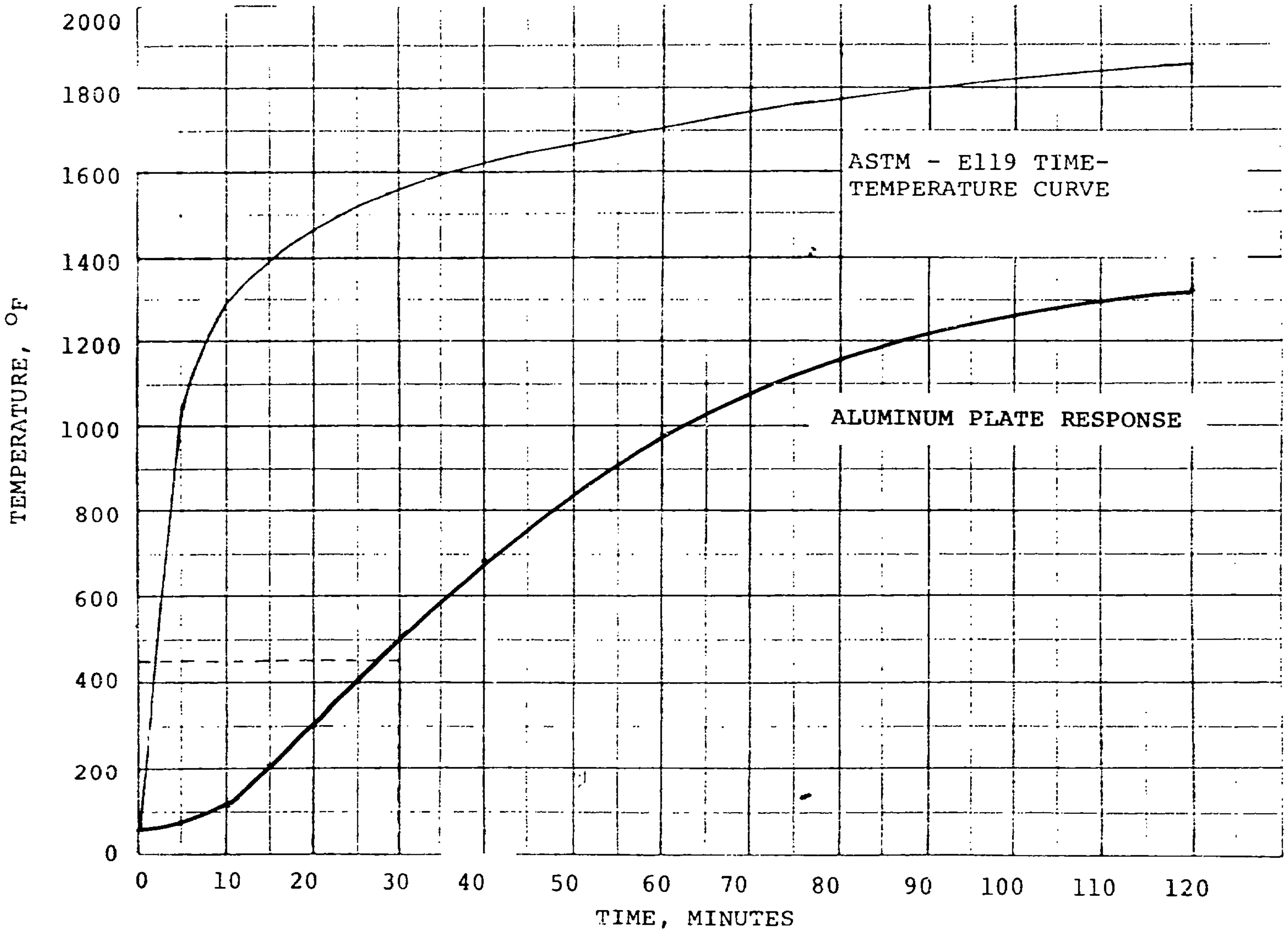
HEATING 5 EVALUATION - CERAFELT -- 1 inch, 4pcf PLUS Aluminum Skin -- 0.05 inch, 168.5 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX C

GRAPH OF RESULTS

HEATING 5 EVALUATION - CERAFELT - 1 inch, 4pcf PLUS Aluminum Skin -- 0.20 inch, 168.5pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

APPENDIX D

SMALL SCALE FIRE TESTING - ASTM-E119 TIME-TEMPERATURE CURVE

DOUBLE INSULATED CONFIGURATION

Material & Description	PSF	Time in Minutes												
		0	5	10	15	20	25	30	35	40	45	50	55	60
CERAFELT - 1-inch 4 pcf	0.33													
Aluminum Plate, °F		82	106	168	238	313	390	468	541	612	683	748	806	860
Average Hot Side, °F		82	462	648	743	797	856	890	927	975	1017	1055	1095	1130
CERABLANKET - 1-1/2-inch 6 pcf	0.67													
Aluminum Plate, °F		79	83	93	134	170	213	260	308	356	404	452	499	546
Average Hot Side, °F		168	906	1147	1241	1331	1390	1435	1467	1501	1533	1563	1588	1609
CERAFELT - 1-inch 8 pcf	0.67													
Aluminum Plate, °F		80	85	123	179	241	304	368	430	490	550	610	668	723
Average Hot Side, °F		171	926	1171	1306	1408	1465	1478	1495	1540	1571	1596	1618	1633
CERAFELT - 2-inch 4 pcf	0.67													
Aluminum Plate, °F		77	79	94	130	171	221	274	327	380	434	488	541	592
Average Hot Side, °F		96	790	1087	1268	1354	1413	1457	1498	1534	1565	1592	1622	1646
CERAFORM 126 - 1-inch 18.5 pcf	1.54													
Aluminum Plage, °F		70	81	114	171	226	280	336	381	447	500	551	599	643
Average Hot Side, °F		101	715	949	1066	1200	1238	1289	1327	1366	1398	1432	1461	1484
KAOWOOL - 1-inch 8 pcf	0.67													
Aluminum Plate, °F		79	84	110	148	195	250	306	353	420	476	530	581	621
Average Hot Side, °F		97	613	880	1039	1133	1200	1259	1307	1338	1367	1393	1415	1437
Flexible MIN-K - 3/8-inch 8 pcf core	0.28													
Aluminum Plate, °F		72	108	167	237	322	405	482	557	626	690	749	806	858
Average Hot Side, °F		120	498	699	826	947	986	1036	1086	1176	1170	1221	1249	1295

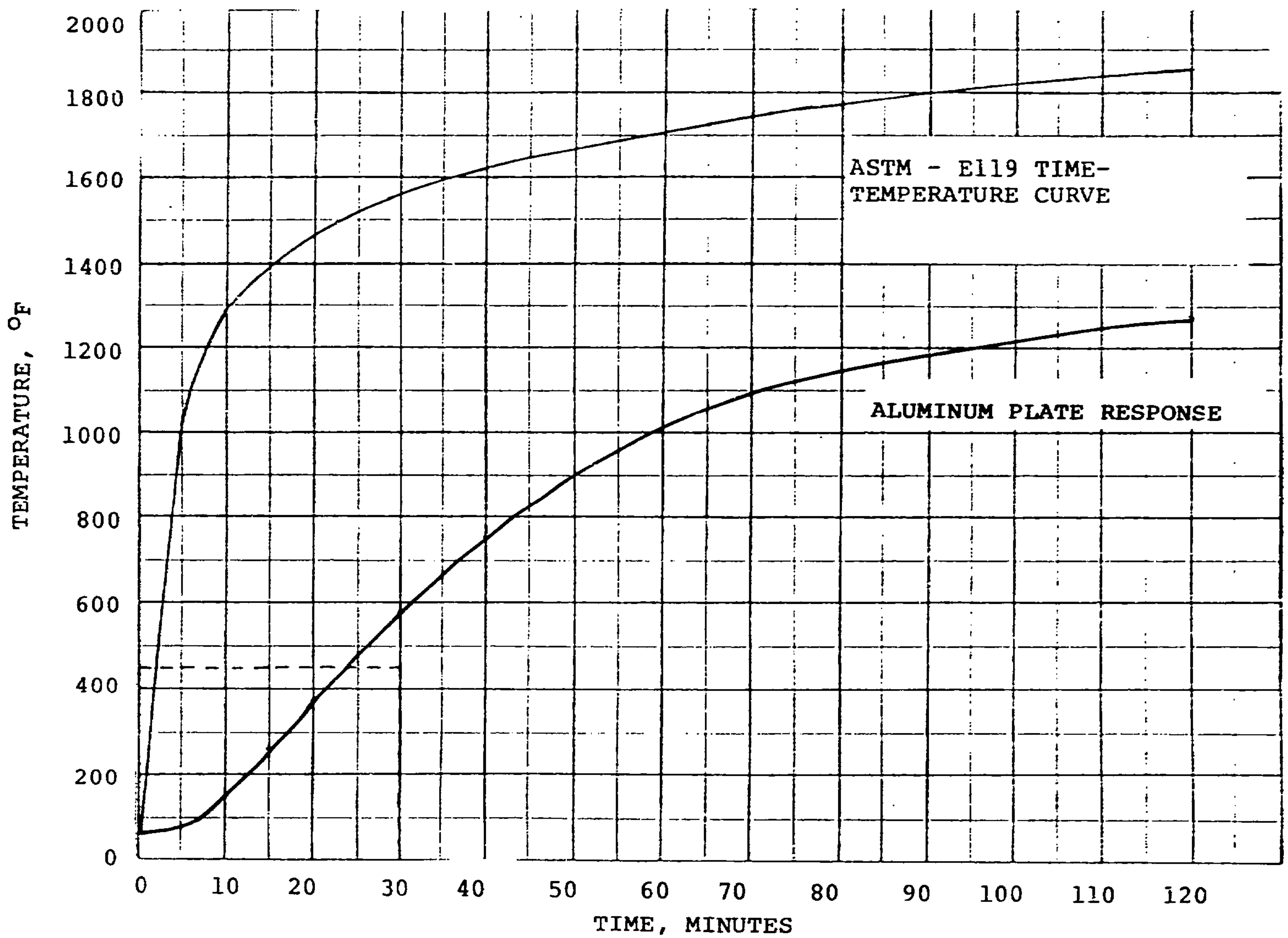
APPENDIX D (Continued)

Material & Description	PSF	0	5	10	15	20	25	30	35	40	45	50	55	60
		Time in Minutes												
MIN-K 2000 - 3/8-In.20 pcf	0.63													
Aluminum Plate, °F		70	88	136	182	231	282	332	382	432	480	528	574	618
Average Hot Side, °F		129	581	651	825	956	1033	1238	1297	1344	1361	1401	1413	1432
MIN-K 1301 - 3/8-In. 20 pcf	0.63													
Aluminum Plate, °F		70	82	112	150	191	236	280	322	364	405	445	484	522
Average Hot Side, °F		201	699	921	1057	1172	1228	1264	1311	1337	1366	1391	1420	1460
MIN-K TE1400 - 3/8-In.20 pcf	0.63													
Aluminum Plate, °F		68	80	113	133	193	238	286	332	377	422	467	510	550
Average Hot Side, °F		170	810	992	1154	1259	1313	1362	1404	1462	1516	1508	1532	1567
Q-FIBER - 1/2-inch, 6 pcf	0.25													
Aluminum Plate, °F		73	99	142	198	264	333	401	469	535	598	656	712	762
Average Hot Side, °F		132	889	1067	1233	1329	1391	1438	1476	1513	1547	1570	1598	1616
KAOWOOL - 1-1/2-inch 8 pcf	1.00													
Aluminum Plate, °F		68	69	75	91	116	144	176	216	257	299	340	382	422
Average Hot Side, °F		118	799	1035	1239	1358	1432	1471	1506	1563	1597	1624	1636	1668
Q-FIBER - 1-inch 6 pcf	0.50													
Aluminum Plate, °F		68	74	92	121	153	188	228	272	315	358	400	441	482
Average Hot Side, °F		137	882	1133	1287	1377	1442	1482	1517	1552	1570	1597	1618	1635
LO-CON - 1-inch 6 pcf	0.50													
Aluminum Plate, °F		66	87	131	181	242	308	374	439	505	568	627	682	733
Average Hot Side, °F		99	873	1012	1143	1243	1308	1346	1406	1433	1460	1487	1509	1524

APPENDIX D

GRAPH OF RESULTS

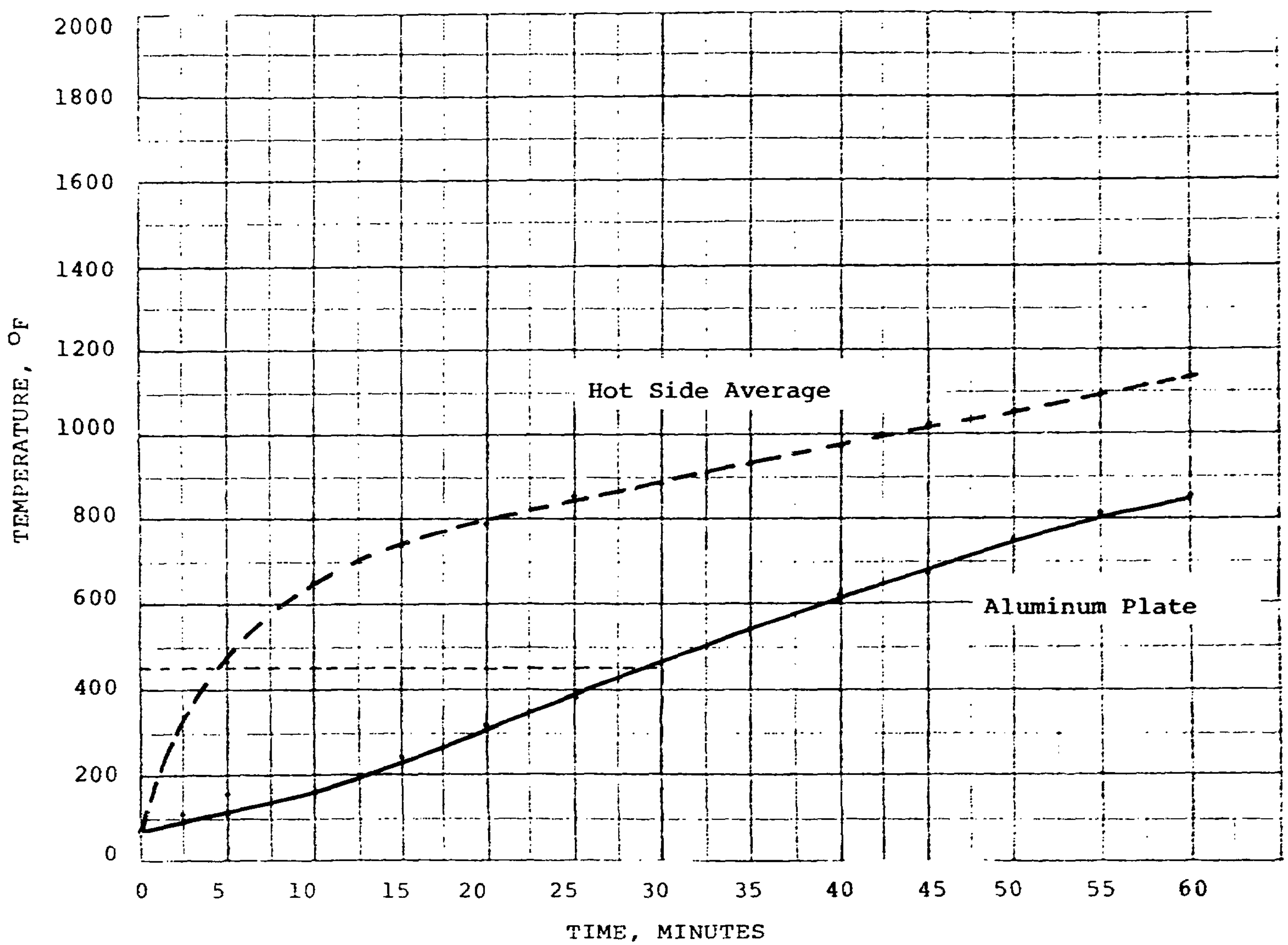
HEATING 5 EVALUATION - LO-CON - 1-Inch, 6 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

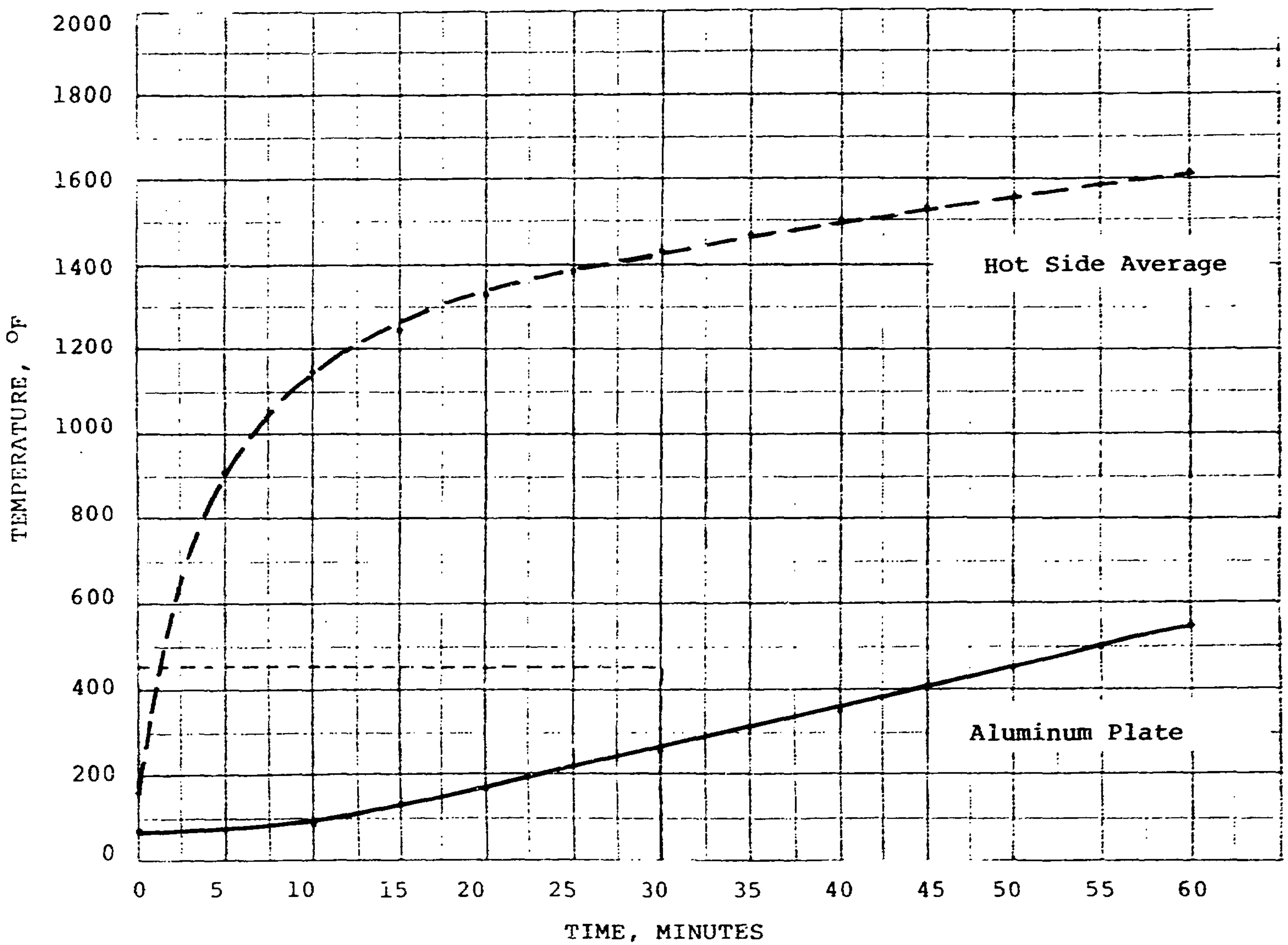
FIRE TEST RESULTS - CERAFELT - 1-inch, 4 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

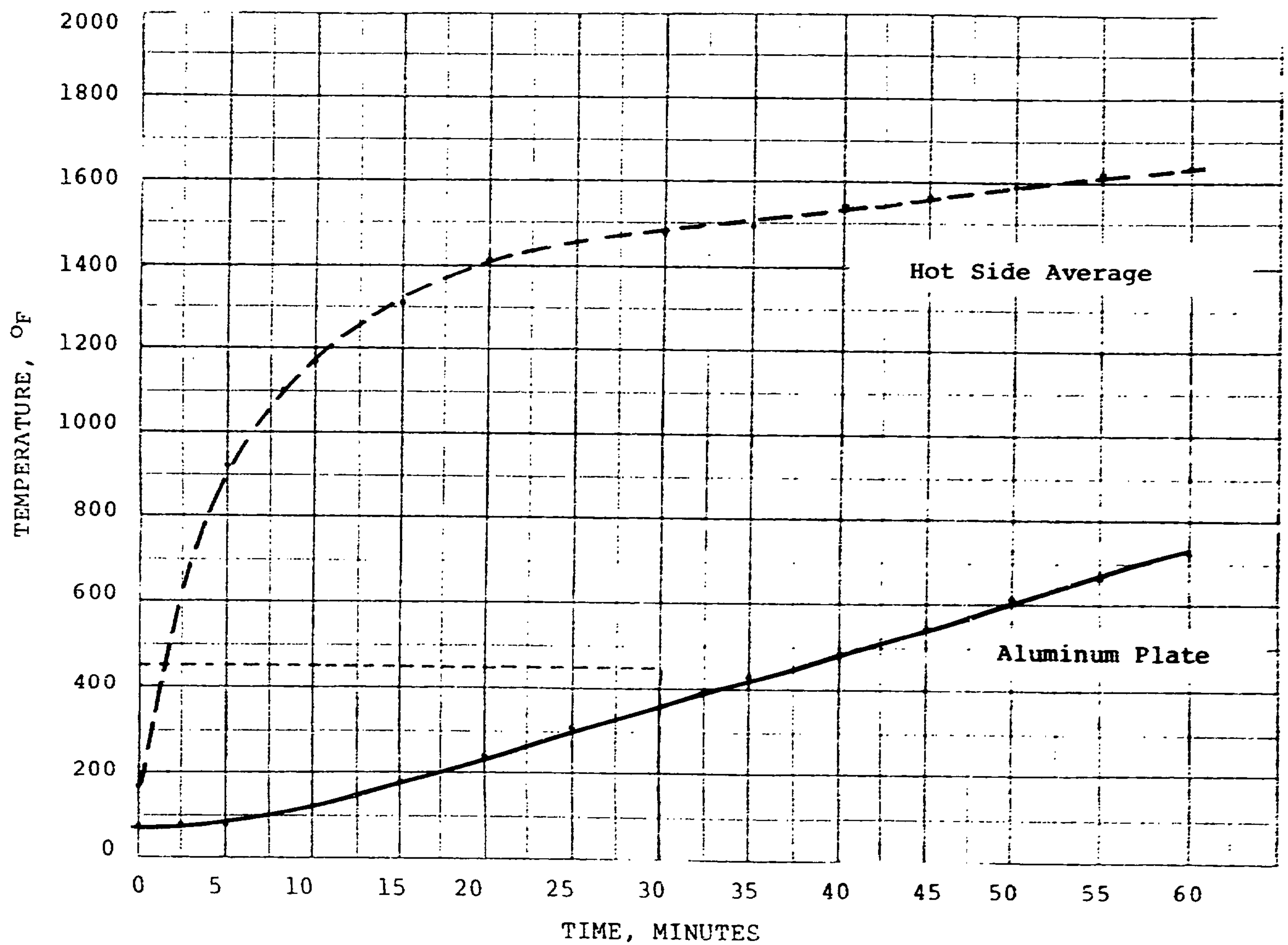
FIRE TEST RESULTS - CERABLANKET - 1-1/2-inch, 6 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

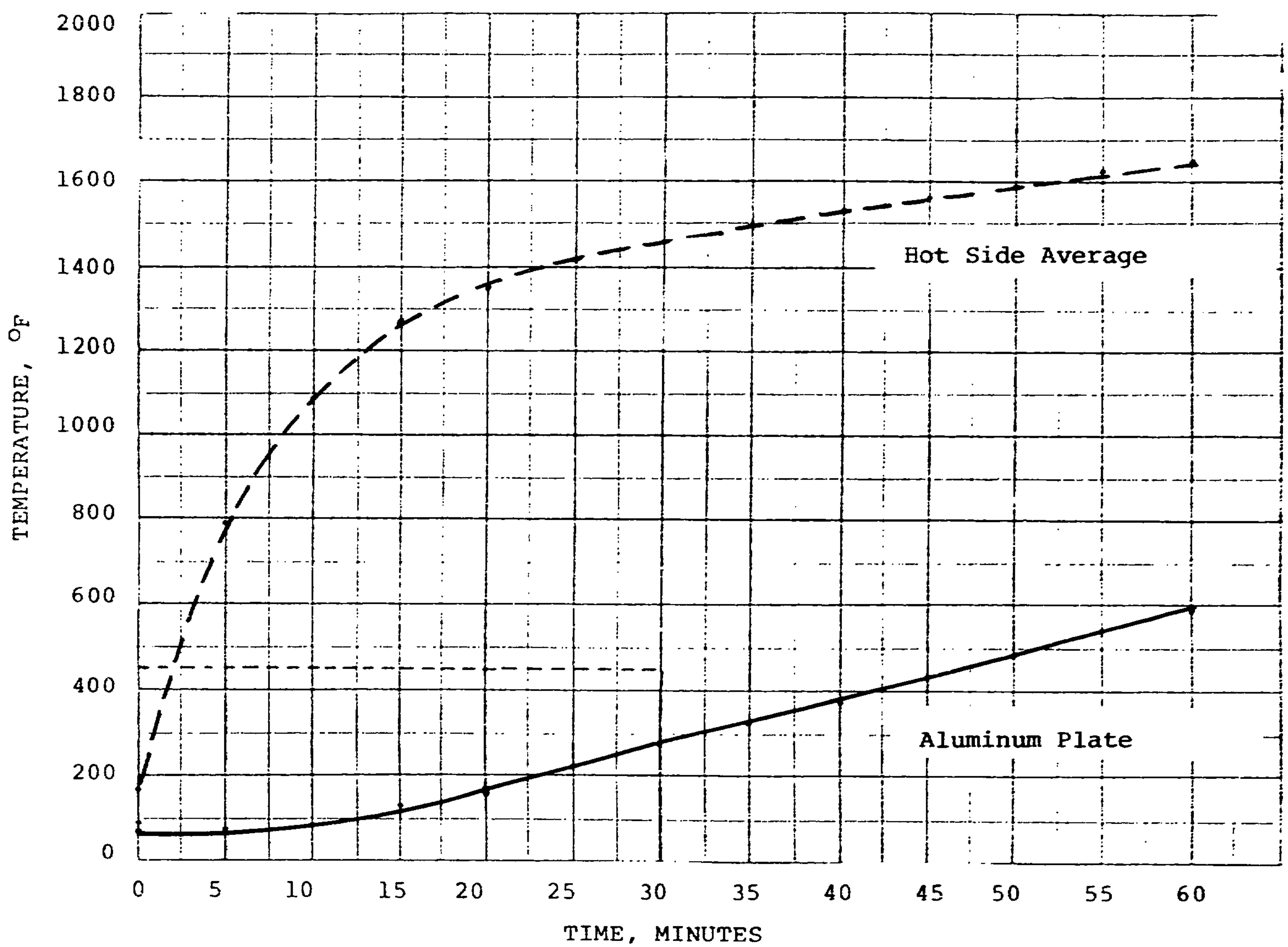
FIRE TEST RESULTS - CERAFELT - 1-inch, 8 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

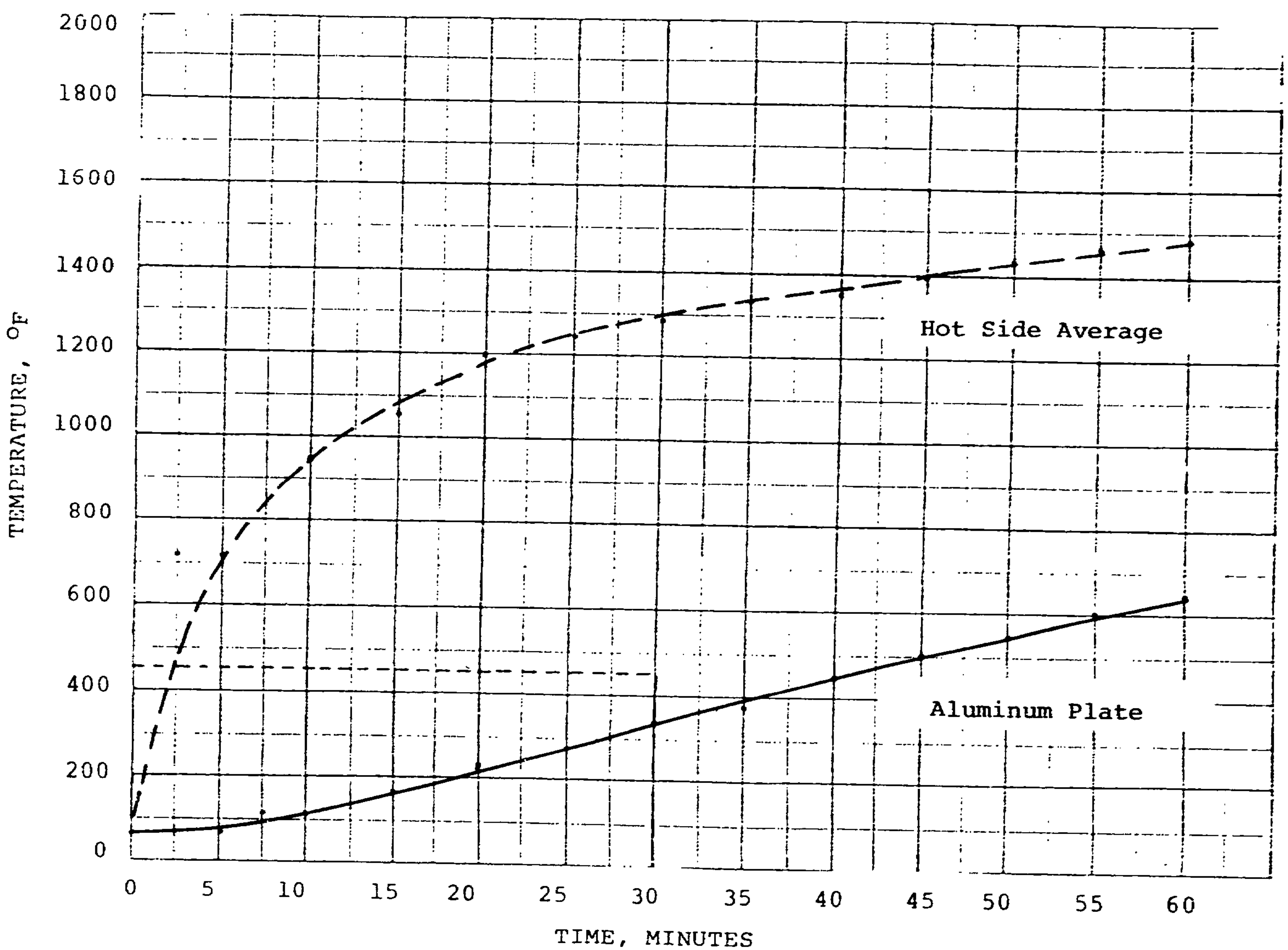
FIRE TEST RESULTS - CERAFELT - 2-inch, 4 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

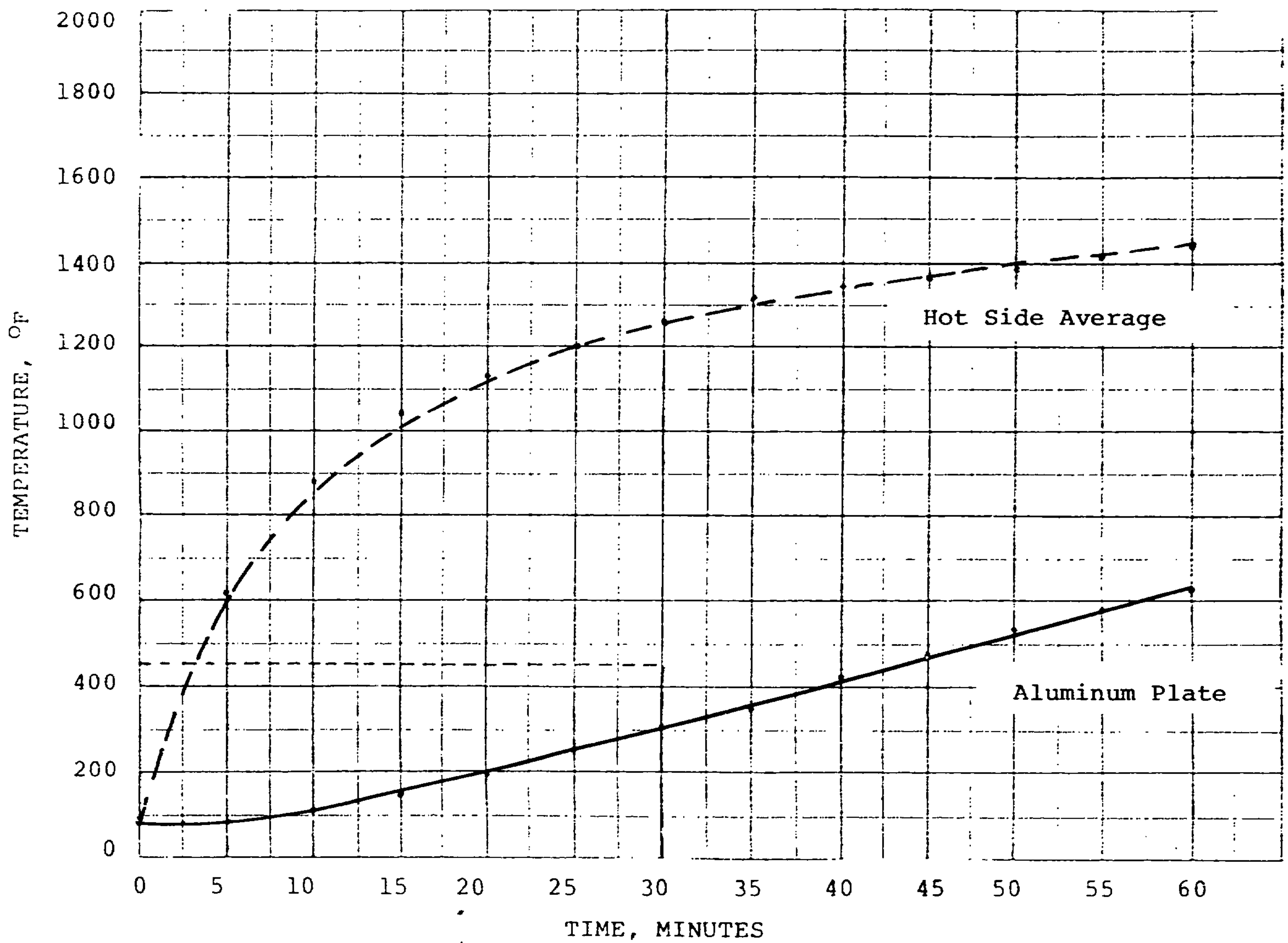
FIRE TEST RESULTS - CERAFORM 126 - 1-inch, 18.5 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

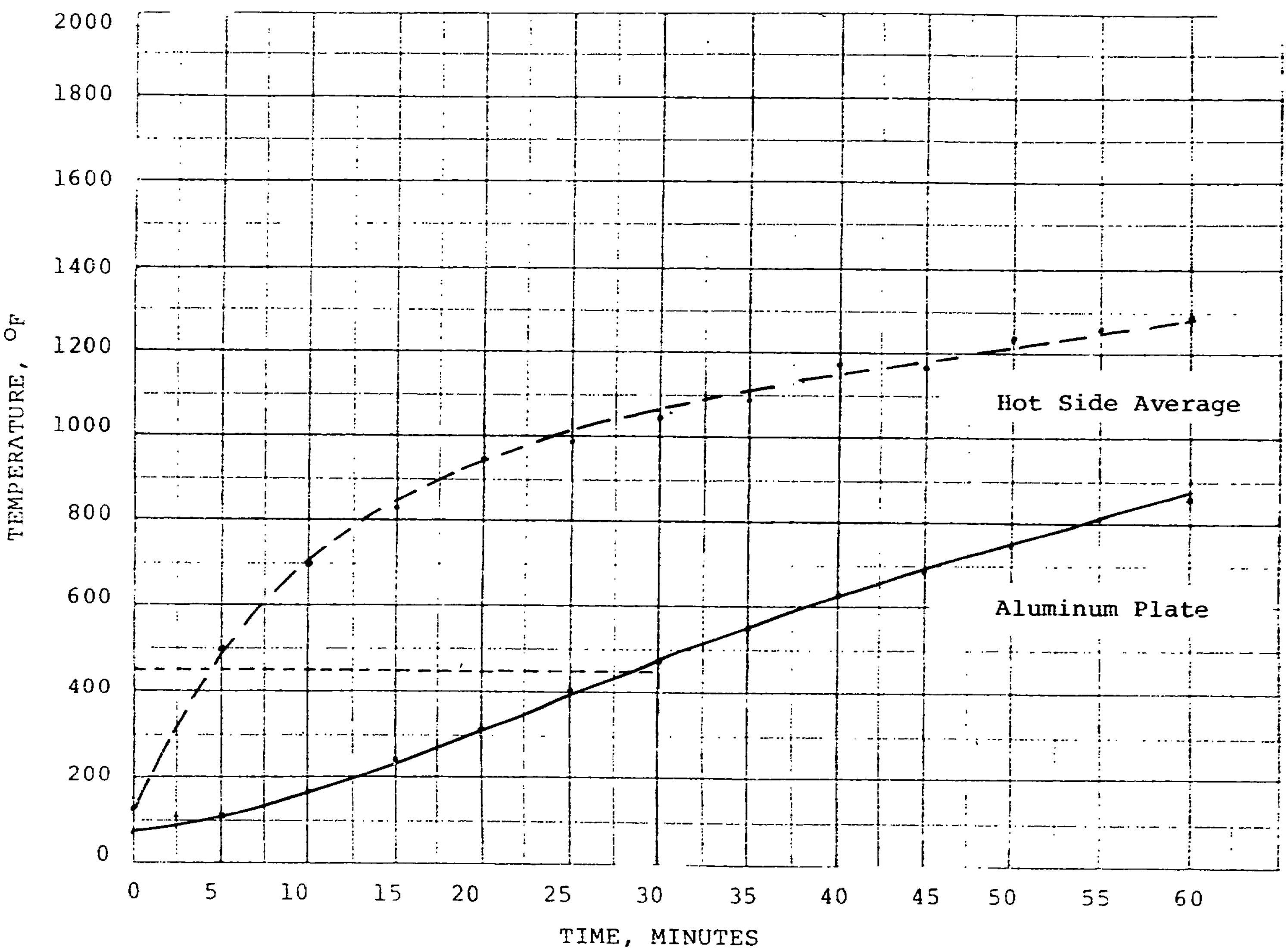
FIRE TEST RESULTS - KAOWOOL - 1-inch, 8 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

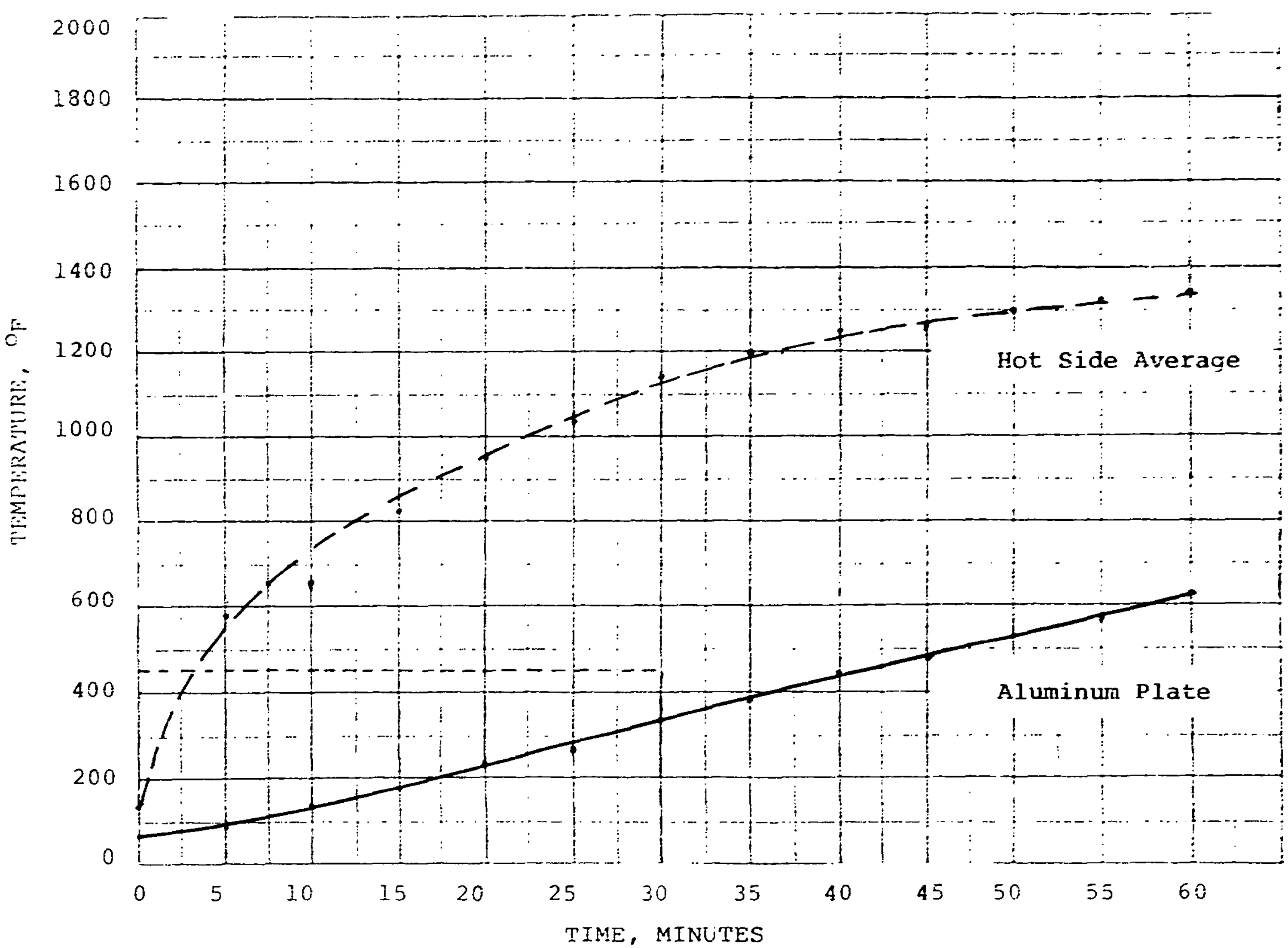
FIRE TEST RESULTS - FLEXIBLE MIN-K - 3/8-inch, 8 pcf Core
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

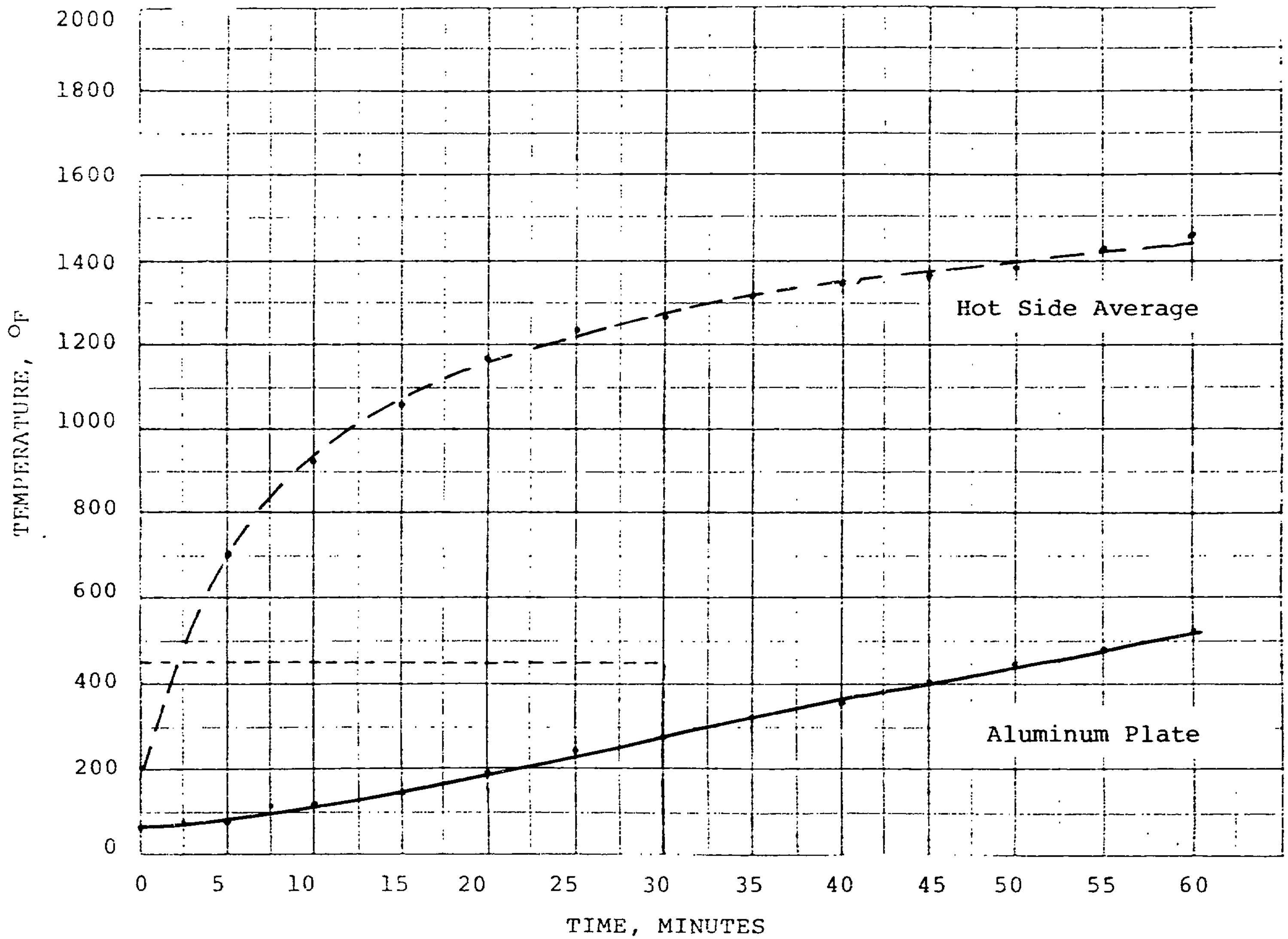
FIRE TEST RESULTS - MIN-K 2000 - 3/8-inch, 20 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

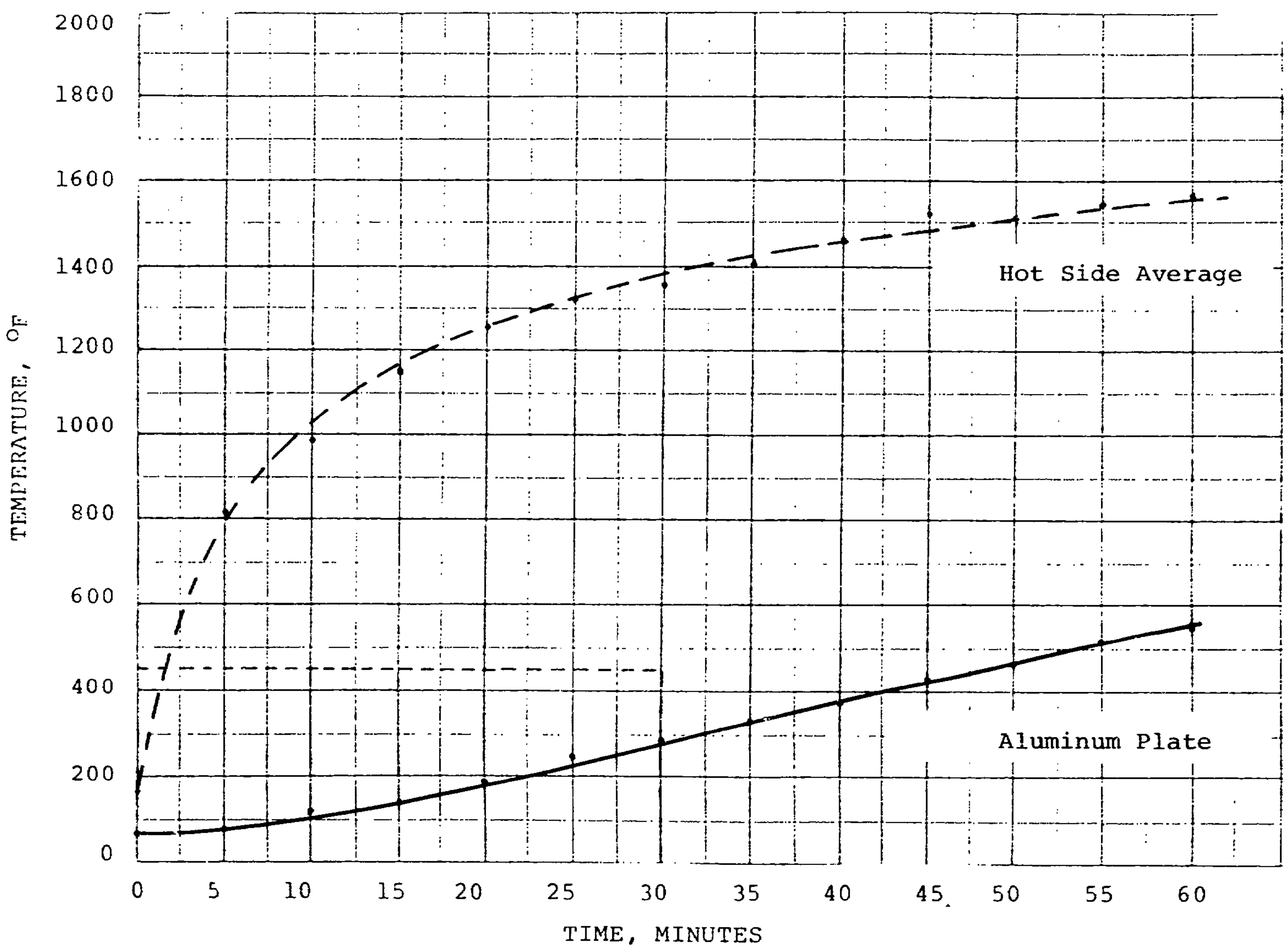
FIRE TEST RESULTS - MIN-K 1301 - 3/8-inch, 20 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

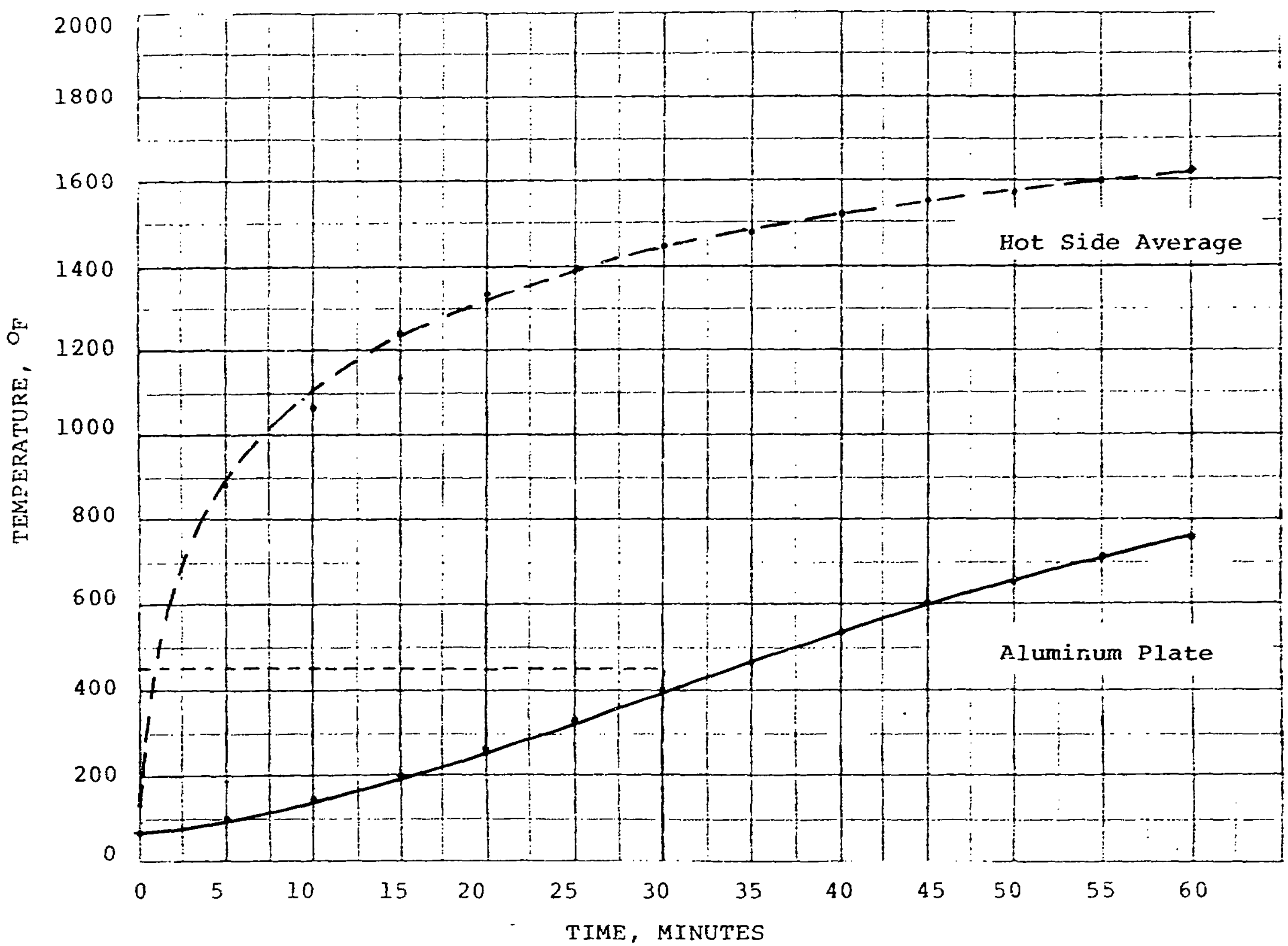
FIRE TEST RESULTS - MIN-K TE1400, 3/8-inch, 20 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

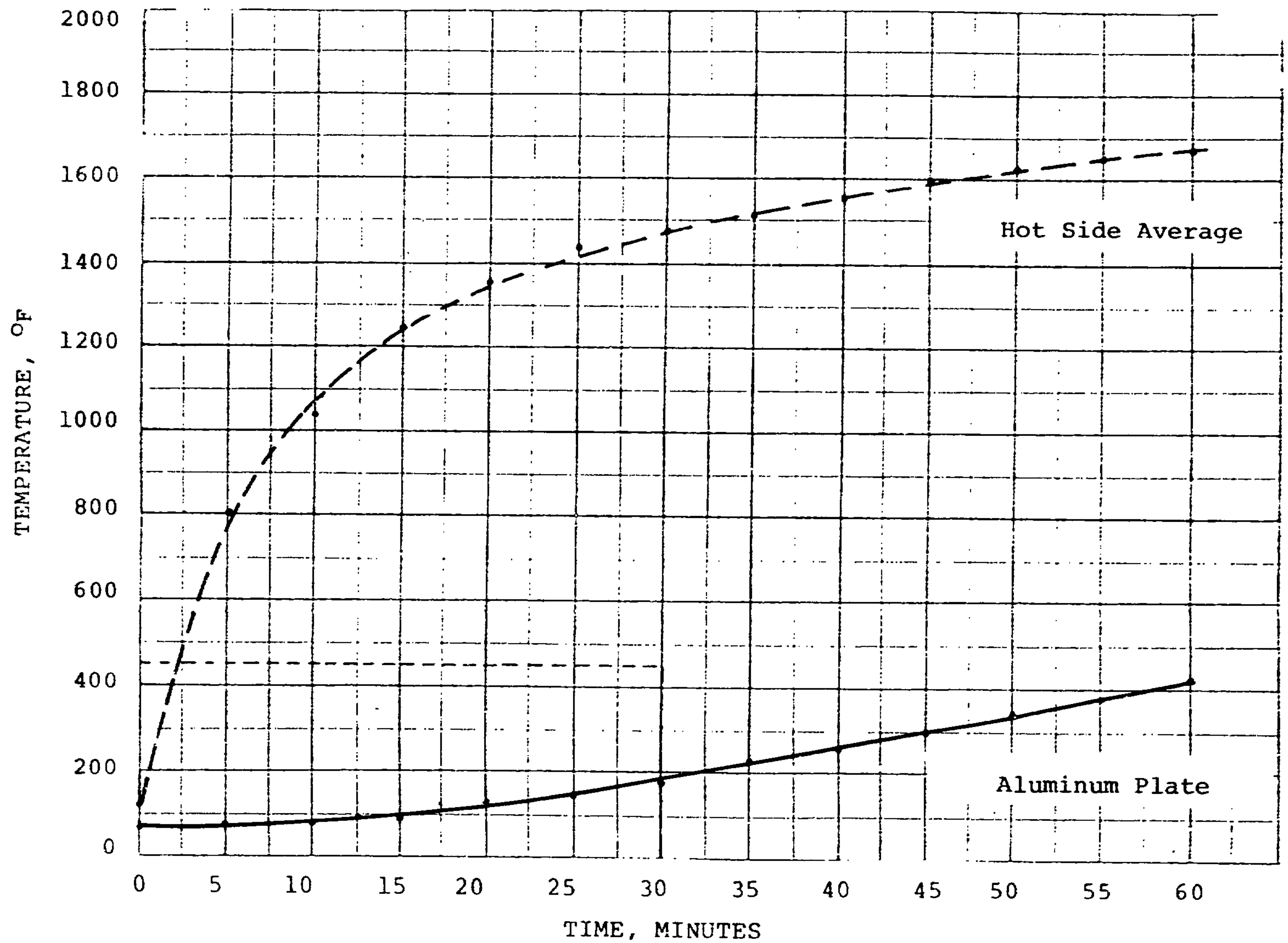
FIRE TEST RESULTS - Q-FIBER - 1/2-inch, 6 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

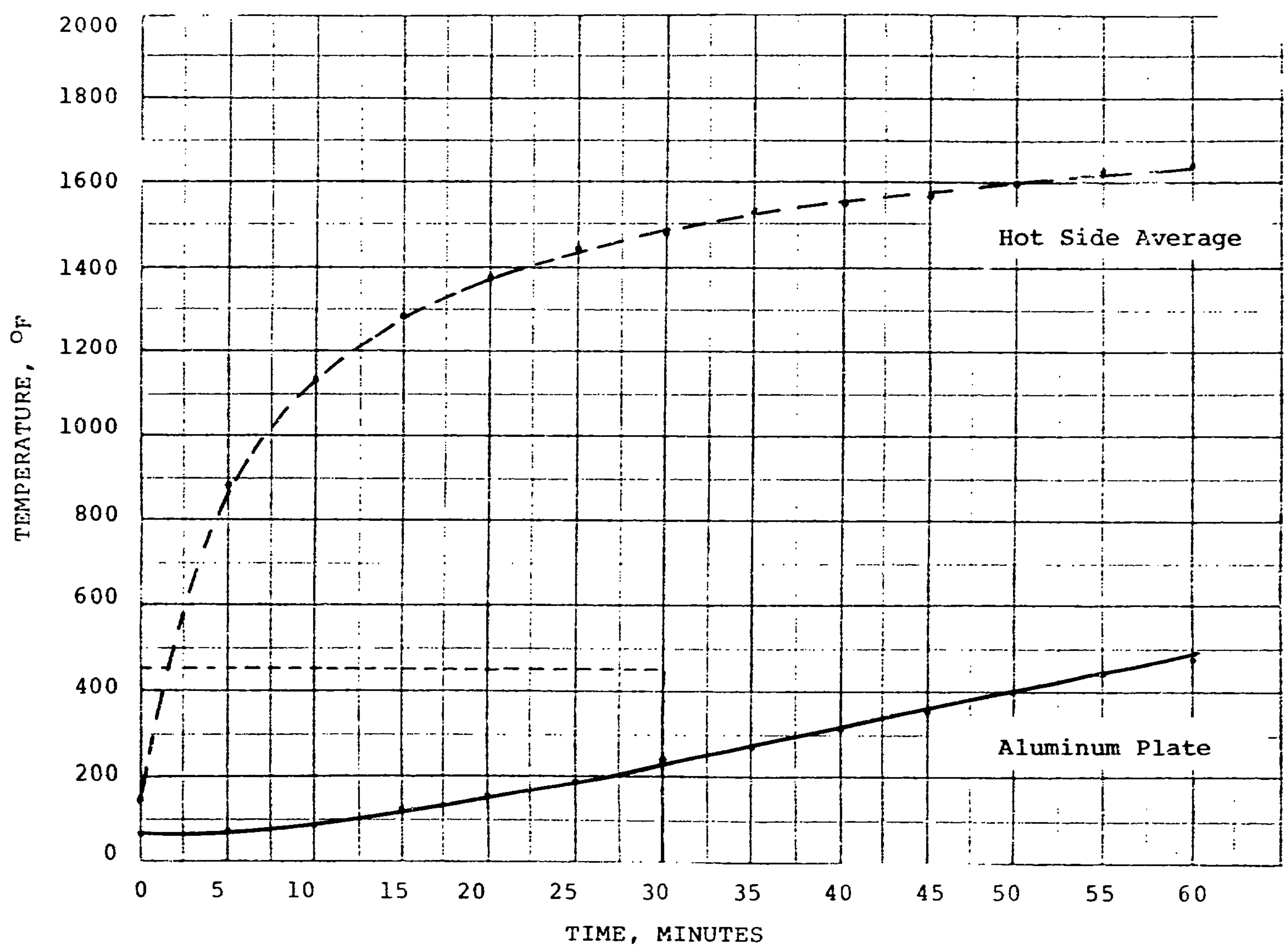
FIRE TEST RESULTS - KAOWOOL - 1-1/2-inch, 8 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

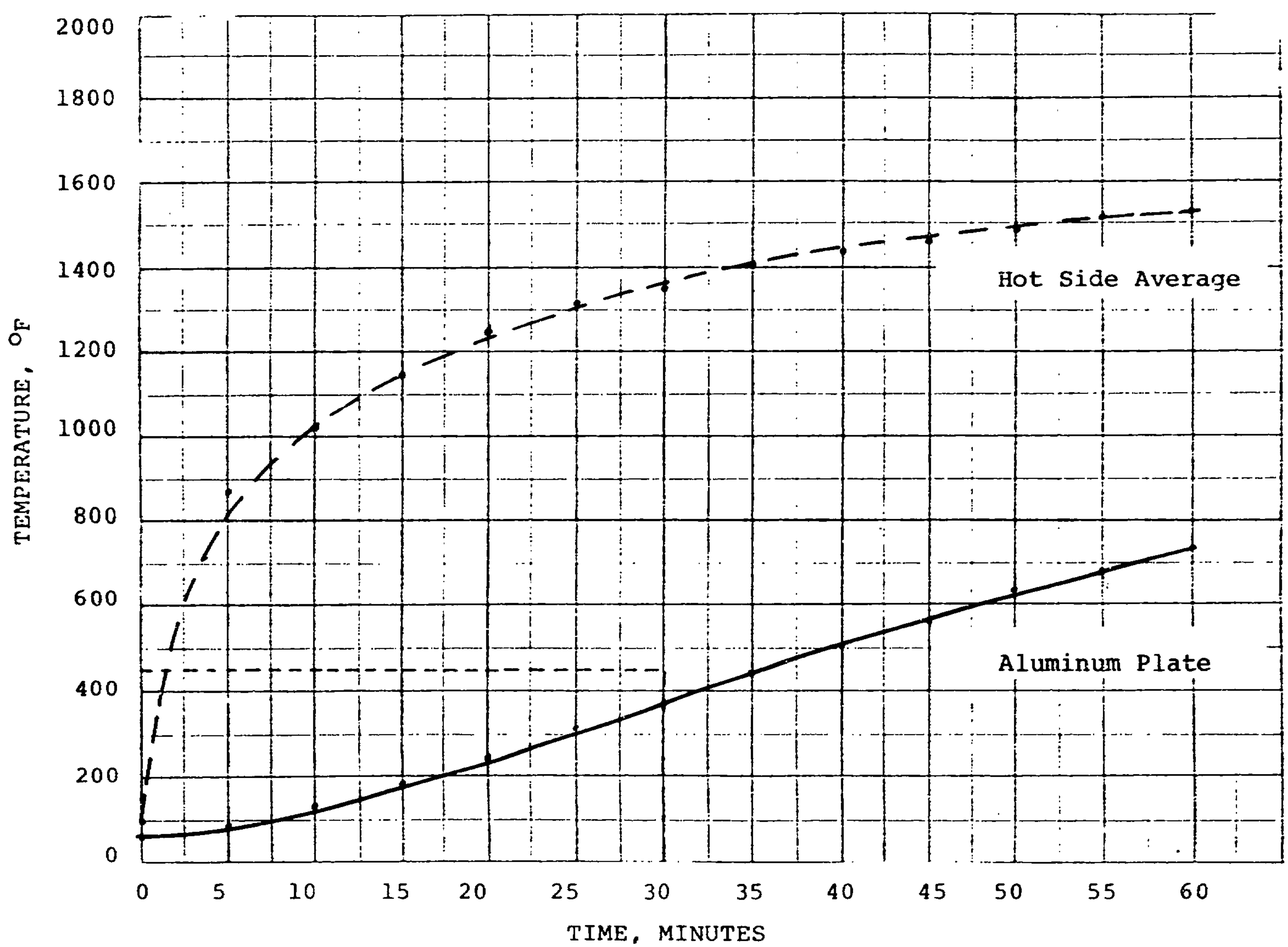
FIRE TEST RESULTS - Q-FIBER, 1-inch, 6 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

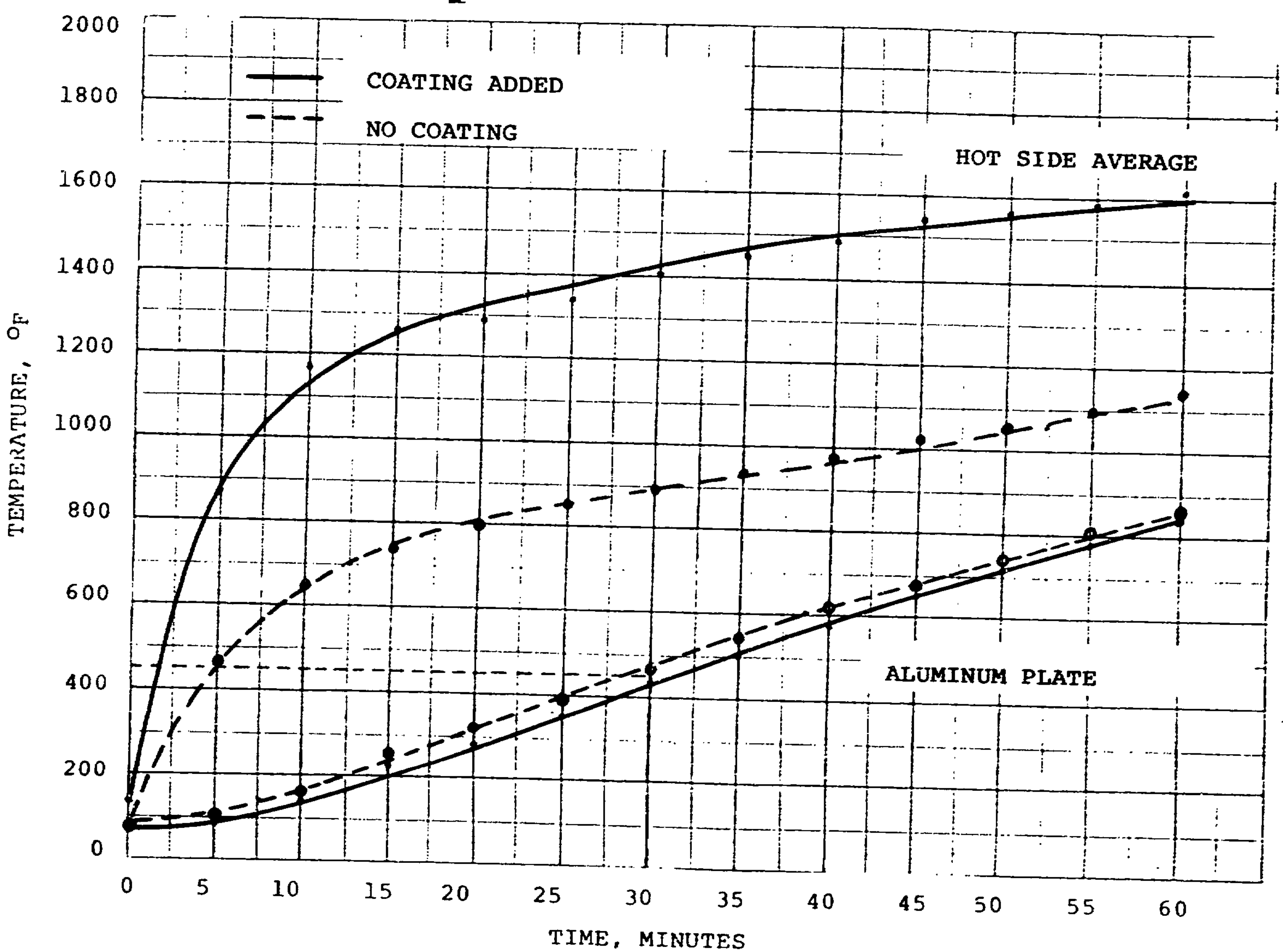
FIRE TEST RESULTS - LO-CON, 1-inch, 6 pcf
DOUBLE INSULATED CONFIGURATION
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

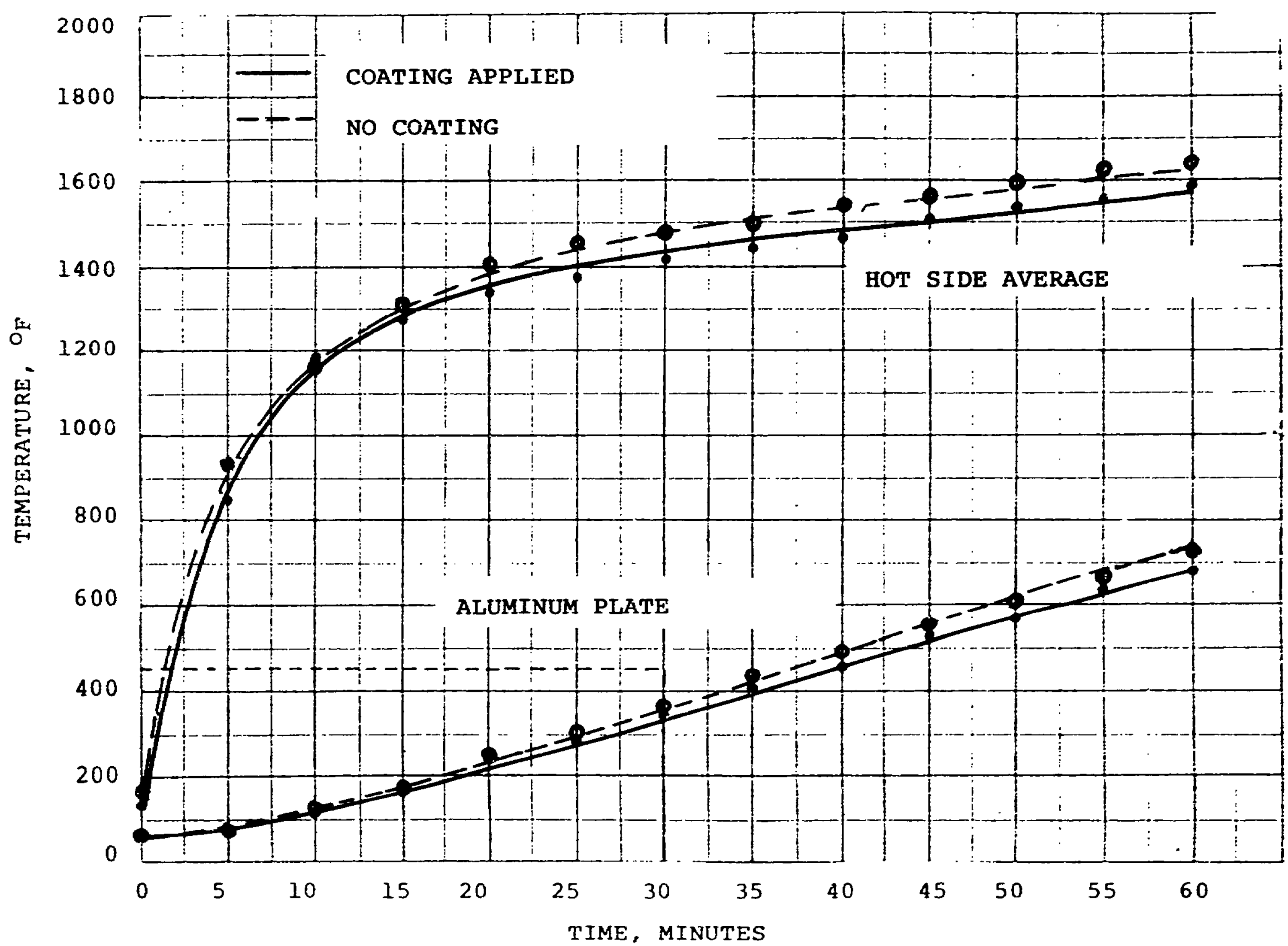
FIRE TEST RESULTS - CERAFELT -- 1 inch, 4pcf
DOUBLE INSULATED CONFIGURATION -- WITH AND WITHOUT INTUMESCENT PAINT COATING
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

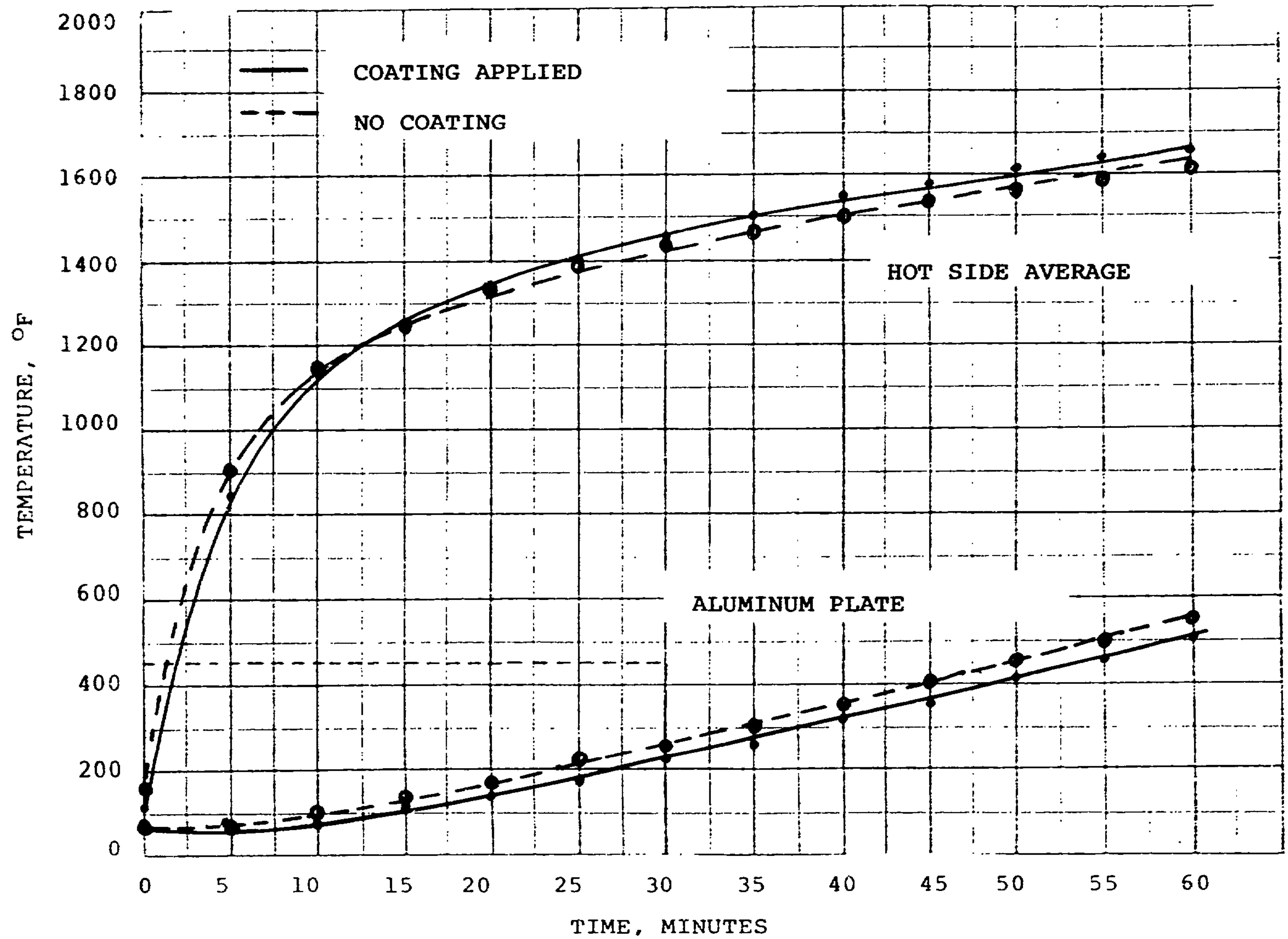
FIRE TEST RESULTS - **CERAFELT -- 1 inch, 8pcf**
DOUBLE INSULATED CONFIGURATION -- WITH AND WITHOUT INTUMESCENT PAINT COATING
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

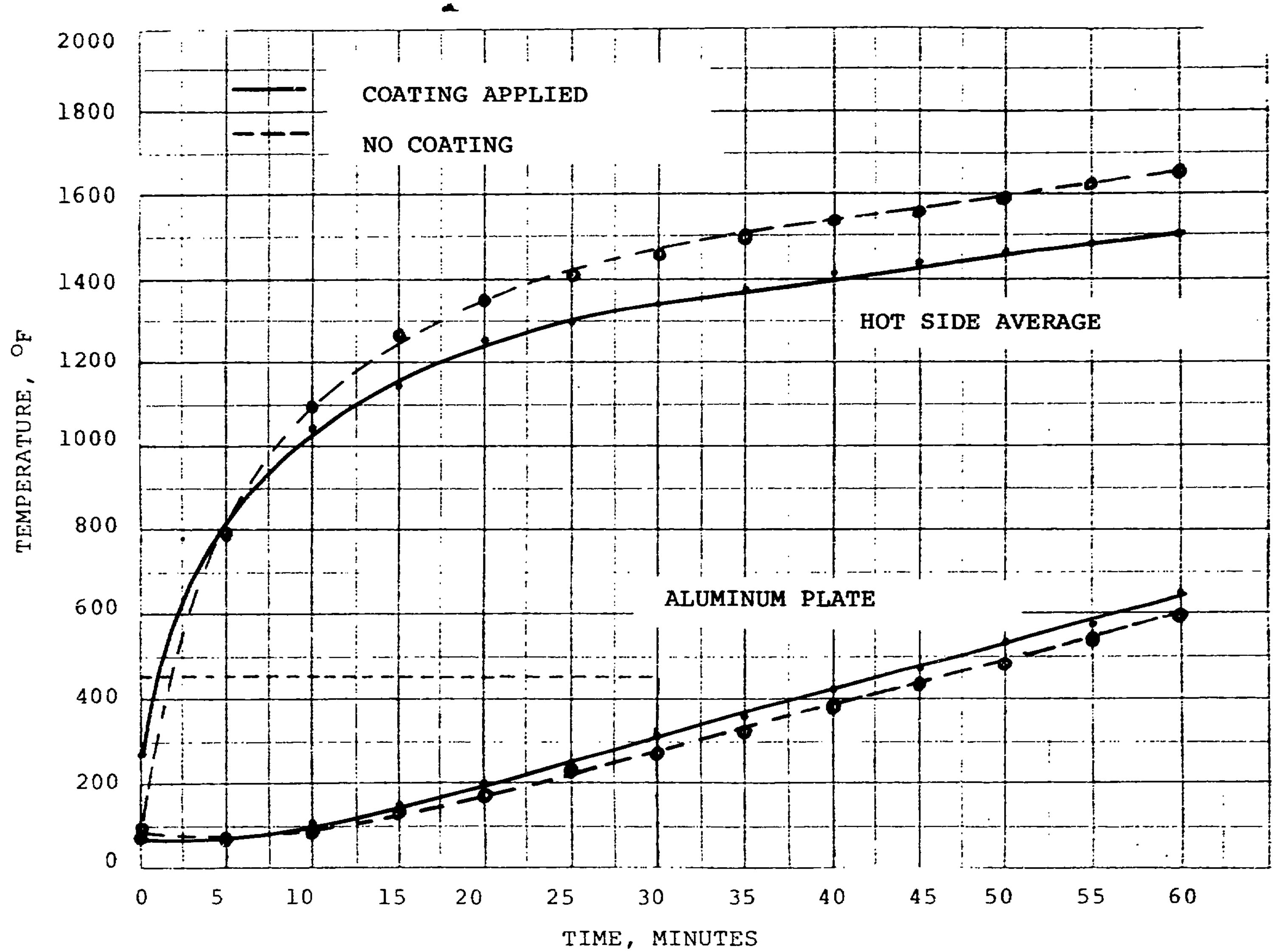
FIRE TEST RESULTS - **CERAFIBER -- 1 1/2 inch, bpcf**
DOUBLE INSULATED CONFIGURATION -- WITH AND WITHOUT INTUMESCENT PAINT COATING
NAVY CONTRACT N00173-80-C-0413



APPENDIX D

GRAPH OF RESULTS

FIRE TEST RESULTS - CERAFELT -- 2 inch, 4pcf
DOUBLE INSULATED CONFIGURATION -- WITH AND WITHOUT INTUMESCENT PAINT COATING
NAVY CONTRACT N00173-80-C-0413



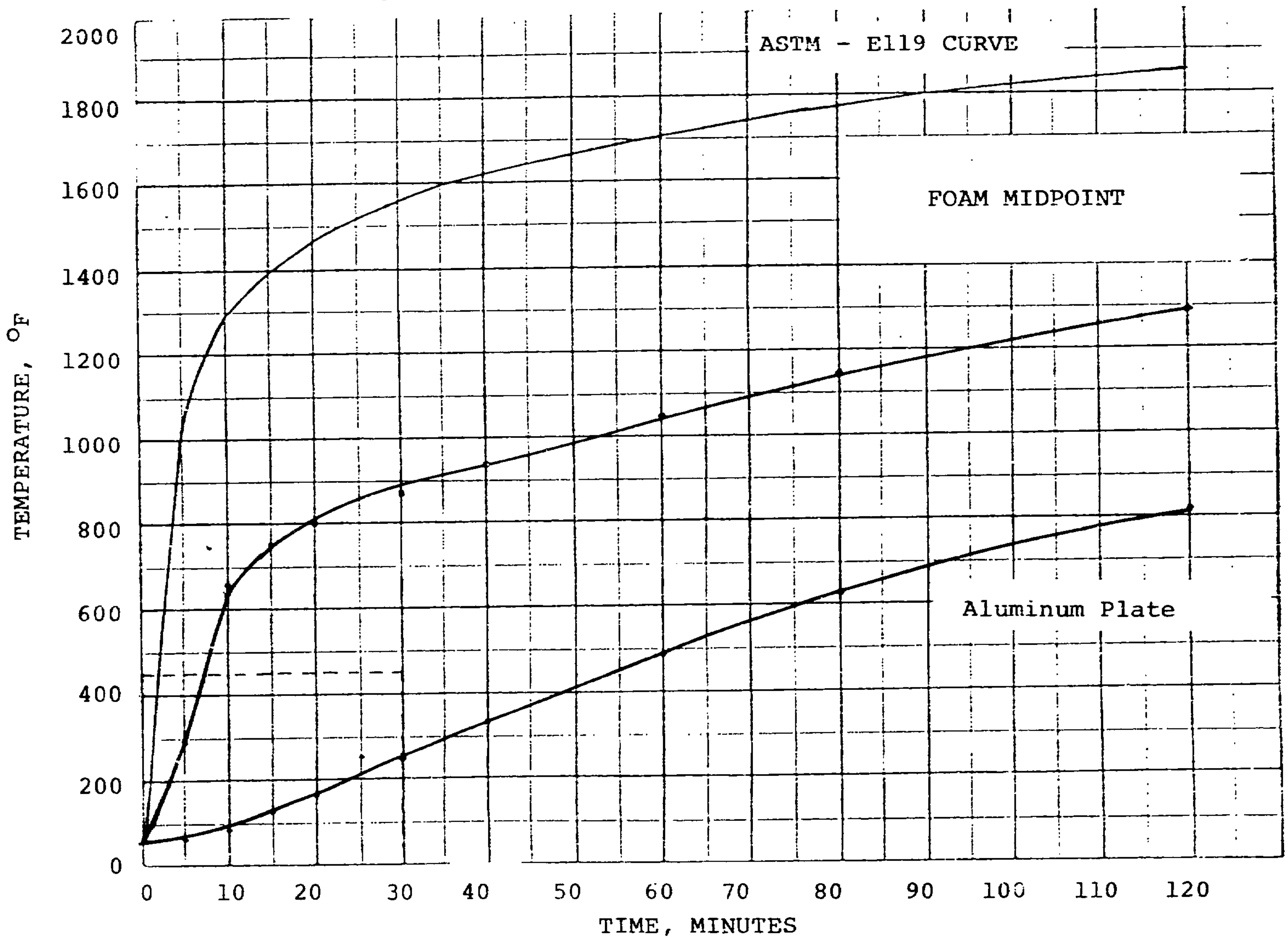
APPENDIX E

APPENDIX E

GRAPH OF RESULTS

HEATING 5 EVALUATION - 1/2-In., 4pcf CERAFELT PLUS 1-In. ISOCYANURATE FOAM

NAVY CONTRACT N00173-80-C-0413

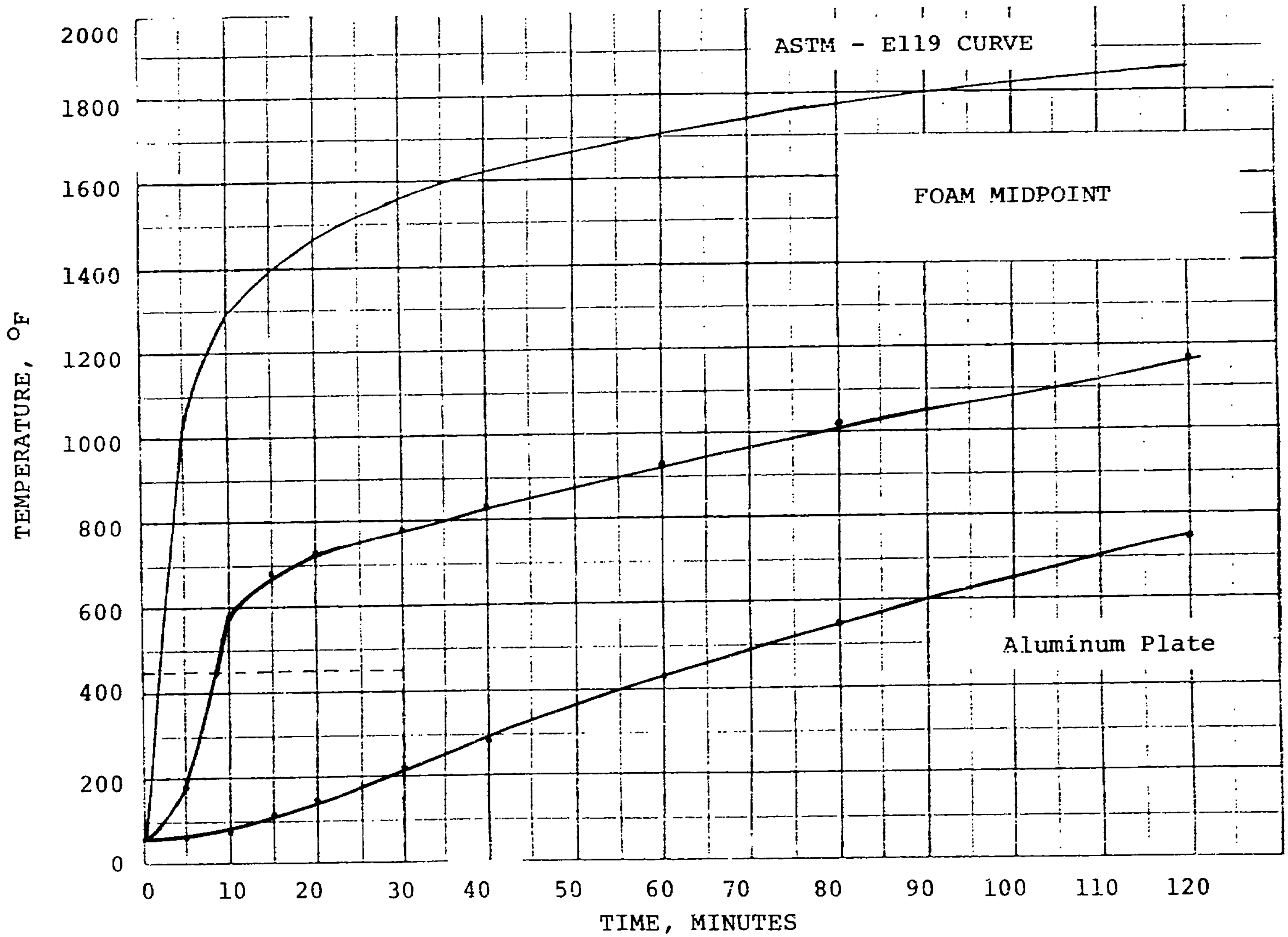


APPENDIX E

GRAPH OF RESULTS

HEATING 5 EVALUATION - 1/2-In. 6pcf Q-FIBER PLUS 1-IN. 4pcf ISOCYANURATE FOAM

NAVY CONTRACT N00173-80-C-0413

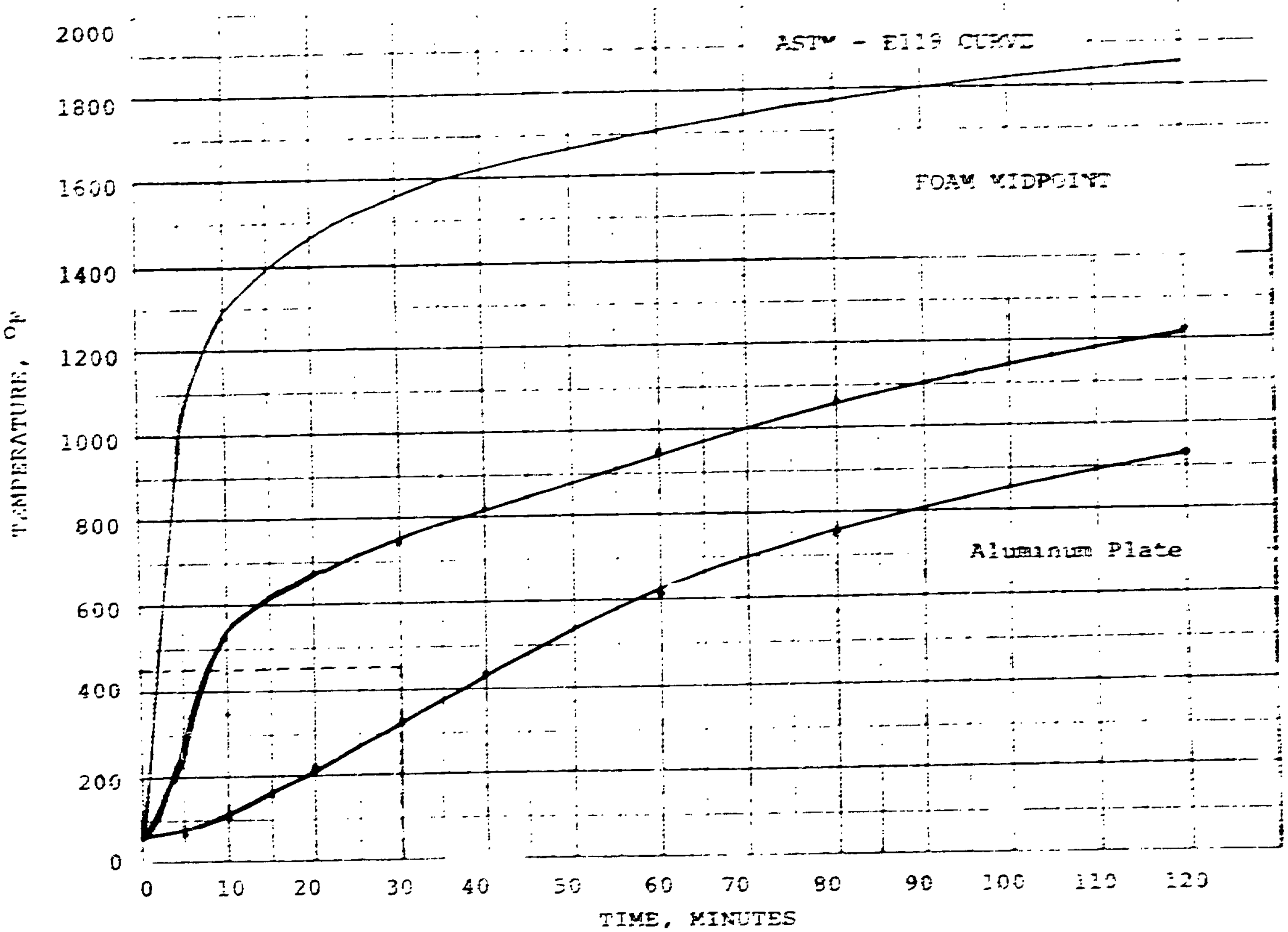


APPENDIX F

GRAPH OF RESULTS

HEATING 5 EVALUATION - 1/2-In. 6pcf Q-FIBER PLUS 1/2-In. 2pcf ISOCYANURATE FOAM

NAVY CONTRACT N00173-80-C-0413

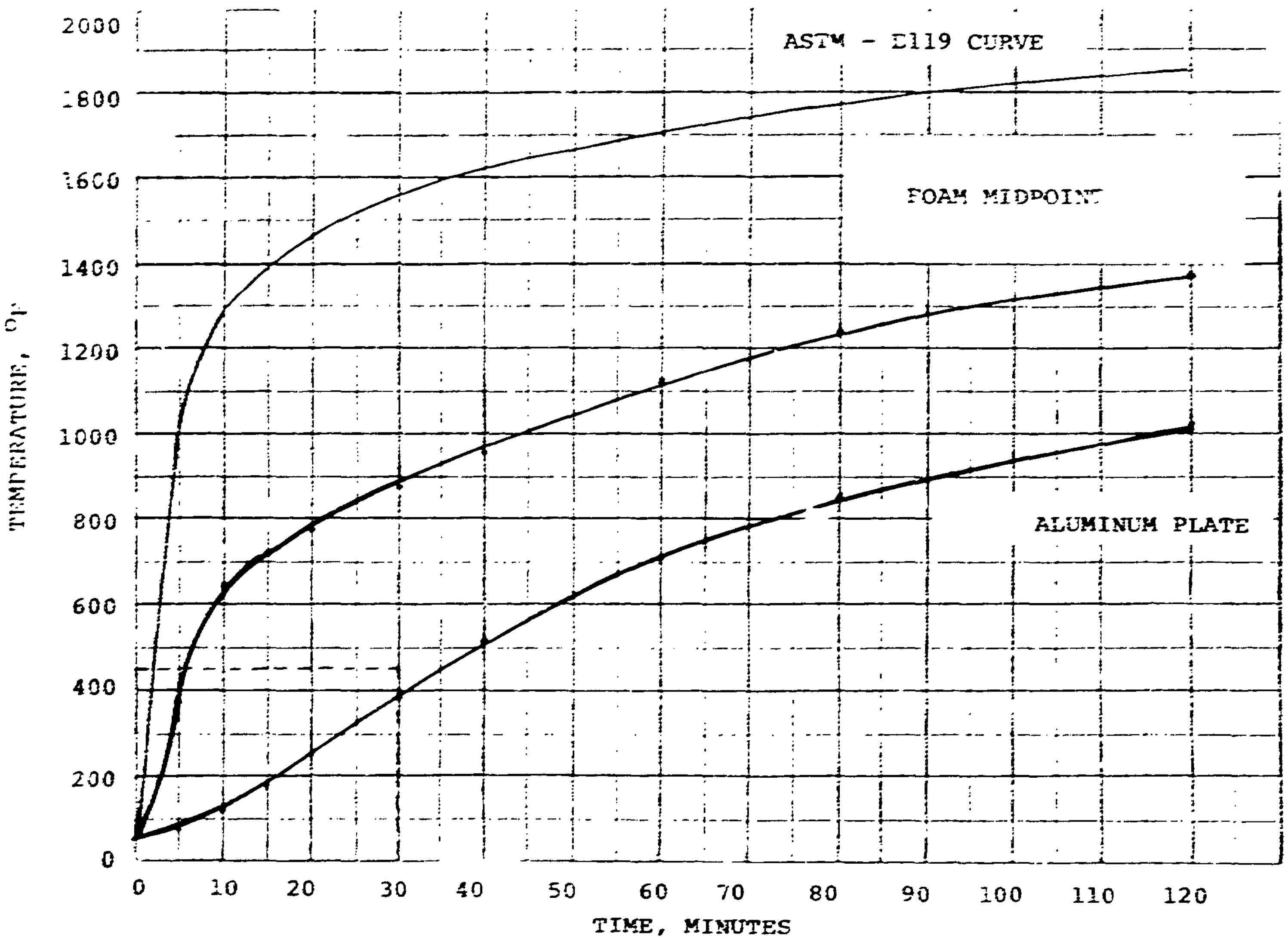


APPENDIX E

GRAPH OF RESULTS

HEATING 5 EVALUATION - 1/2-In.4pcf CERAFELT PLUS 1/2-In.3pcf ISOCYANURATE FOAM

NAVY CONTRACT N00173-80-C-0413

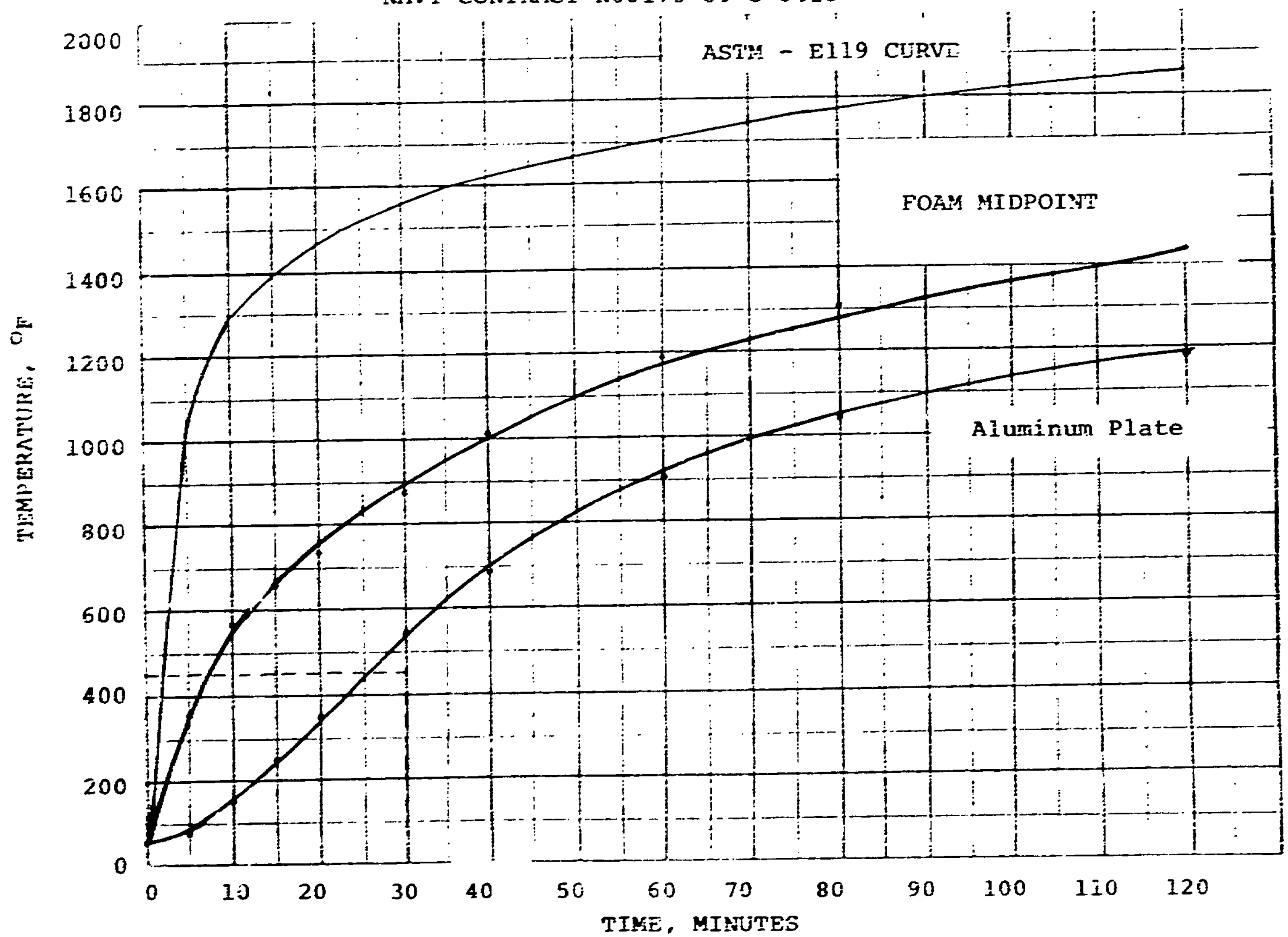


APPENDIX F

GRAPH OF RESULTS

HEATING 5 EVALUATION - 1/2-In.4pcf CERAFELT PLUS 1/4-In.3pcf ISOCYANURATE FOAM

NAVY CONTRACT N00173-80-C-0413

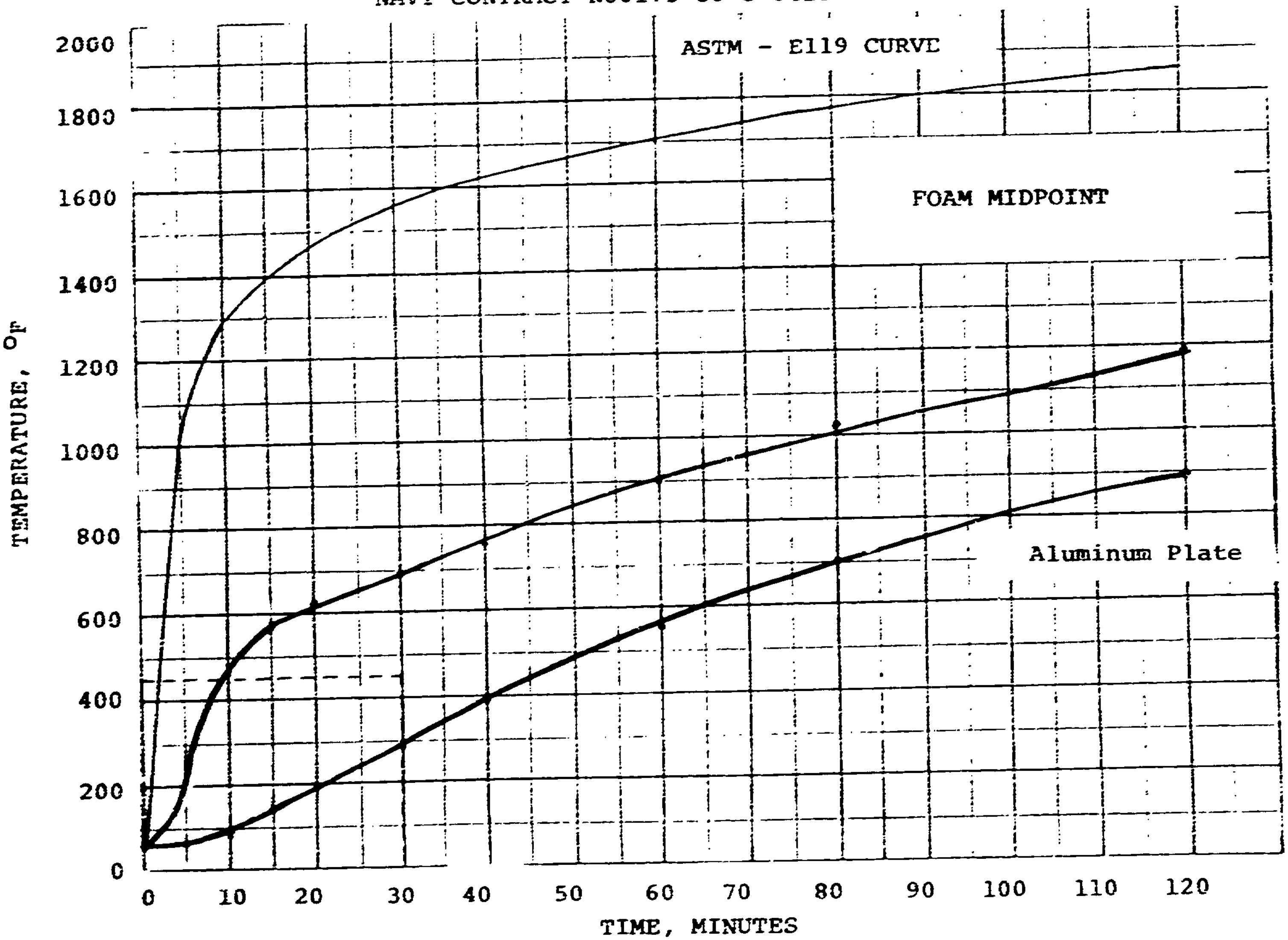


APPENDIX E

GRAPH OF RESULTS

HEATING 5 EVALUATION - 1/4-In.20pcf MIN-K TE1400 plus 1/2-In.3pcf ISOCYANURATE FOAM

NAVY CONTRACT N00173-80-C-0413

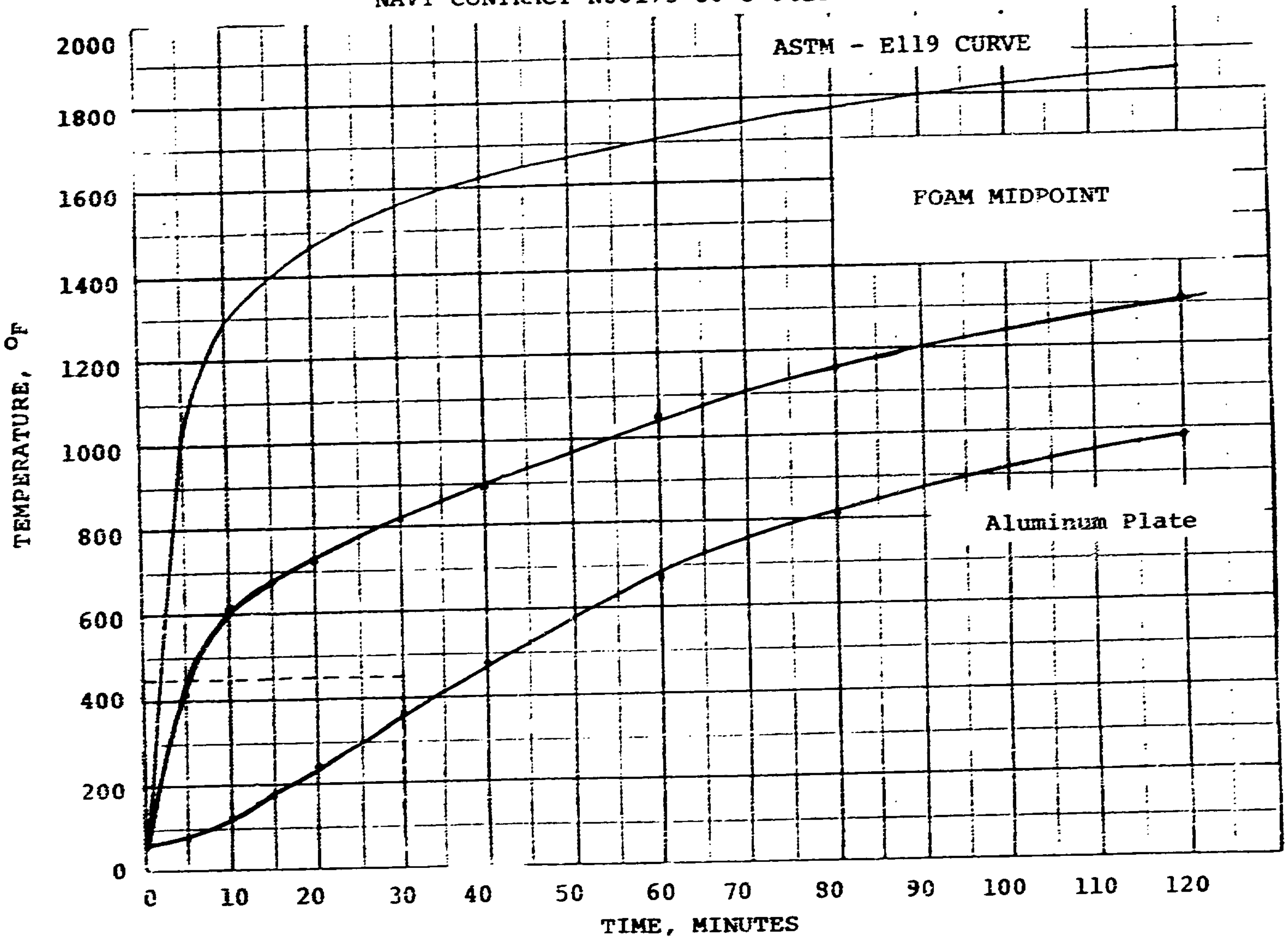


APPENDIX E

GRAPH OF RESULTS

HEATING 5 EVALUATION - 1/4-In.8pcf CORE FLEXIBLE MIN-K plus 1/2-In. 3pcf ISOCYANURATE FOAM

NAVY CONTRACT N00173-80-C-0413



APPENDIX E

GRAPH OF RESULTS

HEATING 5 EVALUATION - 1/4-In.8pcf CORE FLEXIBLE MIN-K plus 1/4-In.3pcf ISOCYANURATE FOAM

NAVY CONTRACT N00173-80-C-0413